UNIVERSITY OF HAWAII
LIBRARY
FEB 13 '62

Publié avec le concours financier de l' U. N. E. S. C. O.

Bulletin volcanologique

ORGANE DE

l'Association de Volcanologie

de l'Union géodésique et géophysique internationale

Publié par le Secrétaire général

FRANCESCO SIGNORE

Série II — Tome XX

Comptes rendus
de la XI^e Assemblée Générale à Toronto
3 - 14 Septembre 1957
II^e Partie

B. V.

NAPOLI
STABILIMENTO TIPOGRAFICO FRANCESCO GIANNINI & FIGLI
Via Cisterna dell'Olio
1959

Printed in Italy

BULLETIN VOLCANOLOGIQUE

Organe de l'ASSOCIATION DE VOLCANOLOGIE
de l'Union géodésique et géophysique internationale.
Série II - Tome XX - 1959

CONDITIONS DE PUBLICATION

1. **Commission de Publication** — La Commission de Publication est constituée par le Comité exécutif de l'Association de Volcanologie de l' Union géodésique et géophysique internationale:

Elections de Toronto, 1957, Président: Prof. A. RITTMANN (Suisse); V. Président: Dr. J. F. SCHAIRER (U.S.A.); Secrétaire général: Prof. F. SIGNORE (Italie); Président Section des Volcans actifs: Dr. M. NEUMANN VAN PADANG (Pays Bas); Président Section de Physique des volcans: Dr. G. S. GORSHKOV (U.R.S.S.); Président Section de Physicochimie des Magmes: Prof. H. KUNO (Japon); Président Section de Paléovolcanologie et Plutonisme: Prof. B. GEZE (France).

2. **Correspondance** — Pour toute communication relative au Secrétariat général de l'Association internationale de Volcanologie et à la rédaction adresser: Prof. F. SIGNORE, Via Tasso, 199. Napoli - (Italie).

3. **Insertions** — Seuls sont insérés, s'il y a lieu, les articles ayant pour auteurs les Membres des Comités nationaux et des Sections volcanologiques et les Volcanologistes délégués officiels aux Assemblées générales de l' Union, *ou les articles d'autres présentés par ces personnalités.*

Les opinions et théories émises n'engagent que leurs auteurs.

Les textes adressés au Secrétaire doivent être *dactylographiés,* au recto seulement, *sous leur forme définitive,* les figures bien dessinées, de préférence sur carton blanc du type bristol, prêtes à être reproduites par clichage typographique. Il est avantageux de les faire dessiner plus grandes qu'elles ne doivent l'être dans le Bulletin.

Les originaux des articles et dessins ne sont pas rendus.

4. **Bibliographie** — Toute publication adressée au Secrétaire fera l'objet d'un compte rendu sommaire analytique (non critique). Les auteurs sont priés de joindre eux-mêmes ce compte rendu à la publication, en lui donnant une étendue proportionnée à l'importance de celle-ci.

(Voir la suite à p. 3 de la couverture)

Publié avec le concours financier de l'U. N. E. S. C. O.

Bulletin volcanologique

ORGANE DE

l'Association de Volcanologie

de l'Union géodésique et géophysique internationale

Publié par le Secrétaire général

FRANCESCO SIGNORE

Série II — Tome XX

Comptes rendus
de la XI^{e} Assemblée Générale à Toronto
3 - 14 Septembre 1957
II^{e} Partie

B. V.

NAPOLI
Stabilimento Tipografico Francesco Giannini & Figli
Via Cisterna dell'Olio
1959

Vient de paraître :

Catalogue of the active volcanoes of the world including solfatara fields

Part VII. KURILE ISLANDS. - By G. S. GORSHKOV. Price $ 5.00

64-04112

Per.
QE
521.5
B 874
ser. 2
v. 20-21

GUSTAV HANTKE

Übersicht über die vulkanische Tätigkeit 1954-1956 *

(Mit 2 Abbildungen)

Während der Jahre 1954-1956 war die vulkanische Tätigkeit allgemein schwächer als 1951-1953. Das bedeutendste Ereignis war der Explosiv- und Effusivausbruch der Besymjannaja auf Kamtschatka 1955-56 und dessen Höhepunkt eine Explosion vom Katmai-Typ am 30. März 1956 mit reichlicher Förderung. Ein heftiger Explosivausbruch bildete im Juli 1955 im südlichen Chile einen grossen Maarkrater; der Merapi auf Java lieferte 1954-1956 viel Lava und weitere grössere Effusionen werden berichtet vom Ngauruhoe (Neuseeland) 1954, Izalco (El Salvador) 1955 und Kilauea 1955. Von 7 Unterseevulkanen im Bereich des Pazifik liegen Ausbruchsnachrichten vor, aber nur in einem Falle (Tuluman, Neu Guinea 1953-55) kam es zu Inselbildungen. 1954 waren 32 Vulkane tätig, davon 14 effusiv, 1955 resp. 34 und 9 und 1956 19 und 8. Diese Liste ist aber nicht vollständig, besonders infolge des Fehlens fast aller Nachrichten aus dem indonesischen Raum.

Nach kurzen Mitteilungen von der Transpacific Expedition des Scripps Institut in La Jolla fand man 1953 im nordwestlichen Pazifik zwischen Kamtschatka und Hawaii einen 900 km langen submarinen Bergrücken vulkanischer Natur, meridional laufend und in mehreren terrassierten Gipfeln bis 2000-1100 m unter den Meeresspiegel ansteigend. Die aus der Tiefe heraufgeholten Gesteinsproben erwiesen sich als dieselben, die man in Kamtschatka, auf den Kurilen und den Aleuten findet: Augit-Hypersthen-Andesit, Augit-Pigeonit-Basalt sowie Tuffe

---

*) **N. D. R. - Dans un prochain B. V. vont paraître plusieurs rapports nationaux.**

von Andesiten und Daziten und Pyroxen-Hornblende-Dazit-Bimsstein (17).

Die Ziffern hinter den Namen der Vulkane sind die Ordnungsnummern nach dem « Catalogue of the active volcanoes of the world including solfatara fields » (I.A.V.), Naples, die eingeklammerten Ziffern beziehen sich auf das Quellenverzeichnis am Schluss.

AMERIKA

Aleutenbogen

Von den Vulkanen des Aleutenbogens liegen aus den Jahren 1954-56 keine Berichte über Eruptionen vor, aber für 1953 wären noch zwei Ereignisse nachzutragen: Am 1. März 1953 um 7.30 sah man eine schwarze Rauchsäule über dem Iliamna (3073 m, Alaska) und im gleichen Jahr war der Kugak (2027 m, nordöstlich vom Katmai) stets dampfend, er hatte am 22. Juli einen Explosivausbruch, wahrscheinlich auch 1951 einen Aschenausbruch (43, 52).

Mexicali

Am 3. September 1955 fand 21 km südlich von Mexicali in Nieder-Kalifornien ein Ausbruch mit niedriger Temperatur statt, dabei entstand eine grosse Spalte, aus welcher Schwefelgase entwichen und heisse Gesteinsbrocken ausgeworfen wurden. Ein ähnliches Ereignis hat schon 1877 in dieser Gegend stattgefunden (62, 67).

Paricutin 14,1-5

Während der Berichtszeit ist der Paricutin in Mexiko ruhig geblieben. Über seine letzte Tätigkeit bis März 1952 ist jetzt der Bericht von Fries und Gutierrez erschienen (20). Danach war die Explosivtätigkeit bis zum 25. Februar noch stark mit reichlicher Förderung von Aschen, Lapilli und Bomben und 3000 m hoch steigenden Rauchsäulen. Bis zum 4. März folgten noch einige schwache Explosionen, aber die Lavaförderung aus der Bocca Nueva Juatita endete schon am 25. II. Der Kegel erreichte eine absolute Höhe von 2808 m und

410 m über der einstigen Niederung, in der er am 20. Februar 1943 entstand. Die Lavaförderung 1952 betrug 15 Mill. m^3.

Insgesamt hat der Paricutin in den 9 Jahren seiner Tätigkeit 0.7 km^3 basaltische Blocklava gefördert, diese bedeckte eine Fläche von 24360 km^2 mit 28.7 m mittlerer und 212 m maximaler Mächtigkeit, Sande und Aschen bedeckten 58682 km^2, Volumen: 1.3 km^3.

Santa Maria 14,2 - 3

1954 und 1955 war der Lavadom Santiaguito an der Südflanke der Santa Maria (3768 m) in Guatemala noch stets dampfend, zeigte aber keine Lavabewegungen mehr. Die stärksten Fumarolen lagen im Nordteil des Doms, die Schwefelgase waren oft bis zur Stadt Quezaltenango wahrzunehmen.

Am 14. April 1956 um 9.00 nach langer Ruhe plötzlicher starker Aschenausbruch aus dem Lavadom, folgend Aschenregen über Quezaltenango und bis El Salvador bis zum 15. IV. nachmittags (38).

Fuego 14,2 - 9

Bei dem starken Ausbruch des Fuego (3835 m) in Guatemala im April 1953 (s. 27, p. 78) ist im Zentrum des 1932 gebildeten Kraters schlackige Andesitlava ausgebrochen und hat sich durch die östliche Randbresche (vergl. die schönen Bilder bei Dozy, Lit. 15) auf den Abhang ergossen, wo sich der Strom in die Hangschluchten verzweigte. Am. 9. September 1954 beobachtete H. Meyer-Abich vom Flugzeug aus noch eine bedeutende Dampfemission auf der den Krater ausfüllenden schwarzen Lavamasse, besonders entlang ihrem Rand.

Im Juli 1955 erfolgte ein kleinerer Ausbruch des Fuego, der aus dieser Lavamasse einen Explosionskrater aussprengte und eine kleine Lavakuppel bildete, wahrscheinlich ist auch ein kurzer Lavastrom nach SO hin abgeflossen (11, 38).

Izalco 14,3 - 3

Im Februar 1954 zeigte der Izalco in El Salvador eine lebhafte strombolianische Tätigkeit: alle 2 bis 15 Minuten erfolgten starke Explosionen mit lauten Detonationen und reichlicher Förderung von Schlacken und Bomben. Später, besonders Mitte des Jahres, sehr schwache Tätigkeit; im Oktober kleiner Lavaausfluss nach der Nordseite aus einer neuen Bocca.

1955 wurde die Tätigkeit stärker und die Förderung bedeutender. Am 24. Februar waren 3 Bocchen tätig, eine warf alle 5 - 15 Minuten Gase, Lapilli und Bomben aus, die beiden anderen nur Gase. Am 28. Februar um 13.00 plötzliche starke Explosion mit Aschenfall in westlicher Richtung und folgendem Lavaerguss aus dem Gipfelkrater, der sich in zwei nach NO und ONO gerichtete Arme teilte. Der Kraterrand im NO wurde zerstört und bei diesem Breschendurchbruch ist eine grosse Absturzglutwolke niedergegangen, die in dem Sattel zwischen dem Izalco und dem Cerro Verde 30 cm hoch Asche ablagerte. Die neue Blocklava war sehr zähe und floss nur langsam. Am 8. März folgten sich die Explosionen alle 3-8 Minuten, deren Wolken stiegen nur sehr langsam auf, sie erschienen jetzt grau und enthielten auch Asche. Im April und Mai nachlassende Tätigkeit, aber häufige Lavanachschübe. In dem breit aufgerissenen Gipfelkrater bauten die Auswürfe einen neuen Zentralkegel auf, dessen Gipfel am 16. Juni schon die Höhe des Kraterrandes erreicht hatte. Vom Juli bis September weitere Lavaergüsse, die ein ausgedehntes Lavafeld mit 5 m Randhöhe am NO-Fuss des Izalco bildeten. Im Oktober beobachtete man auch Lavaaustritte aus Hangbocchen, aber die Explosionen waren schwach, sie folgten sich alle 10 Minuten. Am 3. und 4. November waren zwei neue Lavaströme an der Nordostflanke fliessend und in der Nacht vom 4. zum 5. XI. fanden drei ungewöhnlich starke Explosionen statt, die den NO-Teil des neuen Zentralkegels wegsprengten; auch am 6. XII. um 8.30 starker Ausbruch mit doppelter Rauchsäule und folgendem Sand- und Aschenfall. Ende November hatte der Zentralkegel den alten Krater völlig ausgefüllt und den Zustand wie vor dem 28. Februar wieder hergestellt. Im Dezember keine Lavaergüsse mehr, die Explosionen folgten sich in Abständen von 4-15 Minuten. Die Förderung war ein Olivinbasalt.

Am 3. Januar 1956 wurden dunkle absteigende Glutwolken beobachtet, die den Fuss des Vulkans in 75 bis 80 Sekunden erreichten. Durch reichliche Schlackenauswürfe bildeten sich Glutlawinen und auch die Bresche vom 28. II. wurde völlig zugeschüttet. Am 31. Januar war der Gipfelkrater eine schüsselförmige Depression von nur 76 m Durchmesser, an dessen Boden nur eine Bocca tätig war. Bis Oktober blieb die Explosivtätigkeit gleichmässig, die Ausbrüche folgten sich im Durchschnitt alle 15 Minuten, gefördert wurden Gase, Bomben und Schlacken. Ende Oktober wurden die Ausbrüche stärker, Anfang November erschien wieder Lava im Krater und brach am 3. XI. nach der NO-Seite durch, begleitet von reichlichen Auswürfen glühender Schweisschlacken. Diesmal entstand nur eine kleine Bresche im Kraterrand; die Lava floss über die Ströme von 1955, gabelte sich in halber Höhe der Flanke und war am 26. XI. noch in Bewegung, ein kleinerer Strom floss ausserdem am 10. November nach WNW. Nach dem Lavadurchbruch nahm die Stärke der Explosionen ab, am 24. und 25. XI. entströmten dem Krater bedeutende Wasserdampfsäulen.

Der Kegel des Izalco befindet sich noch in stetem Wachstum. Seine absolute Höhe war nach H. MEYER-ABICH im Juli 1953 1935 m, im September 1955 1950 m, in Januar 1956 1966 m und in November 1956 1978 m (37, 38, 59).

San Miguel 14,3 - 10

Der San Miguel (2132 m) in El Salvador ist in den letzten Jahren sehr ruhig geblieben, nur am 21. Oktober 1954 erfolgten zwei kleine Wasserdampfexplosionen nach vorangegangenen Beben (38).

Telica 14,4 - 4

Der Telica in Nicaragua befand sich 1954 in sehr lebhafter Fumarolentätigkeit, ohne dass es zu Ausbrüchen kam (10).

Las Filas 14,4 - 8

Am 19. Februar 1954 war der am 23. Oktober 1952 entstandene Spaltenkrater (« Hoyo ») des Las Pilas in Nicaragua stärker tätig und stiess ununterbrochen dicht geballte, wirbelnde Dampfwolken von bräunlicher Farbe aus, die sich den Westabhang hinabwälzten, sie verbreiteten einen Geruch nach SO_2 bis zur Stadt Leon. Auch im August beobachtete F. M. Bullard reichliche Dampfemission aus der Spalte. Der am NW-Fuss des Las Pilas gelegene Cerro Negro, zuletzt 1951 eruptiv tätig, hatte leichte Fumarolen im Gipfelkrater und an mehreren noch heissen Stellen in den Lavaströmen am Nordfuss des neuen Ausbruchskegels von 1947 in parallel laufenden meridionalen Spalten. Ende Oktober wieder starker Aschenausbruch aus dem Hoyo-Krater am Las Pilas; die in Leon fallende Asche war von heller Farbe und anscheinend kein frisches Material. Auch im März 1955 war der Hoyo wieder stärker tätig (3, 10, 34, 35).

Momotombo 14,4 - 9

Im Februar 1954 beobachtete Prof. Termer vom Flugzeug aus, wie der Momotombo in Nicaragua in kurzen Pausen geballte graue Rauchwolken ausstiess. Auch sonst zeigte der Vulkan 1954 eine lebhafte Solfatarentätigkeit in seinem Gipfelkrater (3, 10).

Masaya 14,4 - 10

Der Masaya (660 m) in Nicaragua hat von 1947 bis 1954 mehr Schwefelgase gefördert, als irgend ein anderer Vulkan auf dem Erdball. In den letzten Jahren hat diese Gasemission aus dem Schacht Santiago noch zugenommen. Im Oktober 1954 fand McBirney diesen Schacht 225 m tief, in seiner Umgebung waren Senkungen erfolgt (10, 34).

Concepcion 14,4 - 12

Der Vulkan Concepcion (1557 m) auf der Insel Omotepe im Nicaraguasee befand sich von 1948-1955 in ständiger leichter

Explosivtätigkeit. 1954 folgten sich die einzelnen Ausbrüche in Abständen von etwa 30 Minuten, sie warfen gelbliche Rauchwolken mit nur wenig Asche aus (10, 34).

Poás 14,5-4

1954 war der Poás (2722 m) in Costa Rica weiter periodisch explosiv tätig, aber die Ausbrüche waren von verschiedener Stärke. Im März beobachtete Prof. TERMER dichte braune Rauchwolken und im August fand F. M. BULLARD an der Stelle des früheren Kratersees im Mittelkrater einen neuen, etwa 30 m hohen Zentralkegel mit einem explosiv tätigen Gipfelkrater und kleinen, dampfenden Seitenkratern. Die Ausbrüche förderten braune Kumuluswolken mit reichlich Wasserdampf und Lavablöcken, Glut konnte nicht beobachtet werden. Aus einem der Seitenkrater traten bläuliche, durchsichtige Gase aus, SO_2 machte sich weithin bemerkbar und schädigte die Vegetation. Der Südkrater des Poás und sein See blieben unbeeinflusst. Abb. 1 zeigt den tätigen Mittelkrater des Vulkans im August und Abb. 2 den Poás in Tätigkeit im November 1954.

Ende 1954 und im Januar 1955 stiess der Vulkan in unregelmässigen Abständen von einigen Tagen bis zu mehreren Wochen gewaltige Aschenwolken aus, die von dem fast ständig wehenden Nordostwind nach der westlichen Meseta Central verfrachtet wurden. Stieg die Ausbruchssäule sehr hoch, so zog ihr oberer Teil in entgegengesetzter Richtung weg. Im Januar fand Dr. WEYL den Vulkangipfel stark mit schwarzer Asche bedeckt; dem Zentralkegel entstiegen weisse und graue Dampfwolken und auf dem Kraterboden herrschte eine kräftige Solfatarentätigkeit. Im April, Mai und Juni wurden häufig lange Rauch- und Dampffahnen beobachtet und Anfang Juli fanden täglich Wasserdampfexplosionen statt, SO_2-haltige Asche fiel auf den Vulkanberg.

Auch 1956 häufige Rauchemission des Poás wie in den vorgangenen Jahren, besonders in August wieder lange Rauchfahnen nach W und SO_2-haltige Aschenfälle (2, 3, 10, 11, 34, 58).

Irazú 14,5-6

Der Irazú (3452 m) in Costa Rica zeigte 1954-56 nur Solfatarentätigkeit in den Kratern G und M. Am 1. September 1954 war die Dampfemission pulsierend, aber ohne Getöse, die Dämpfe enthielten reichlich SO_2, viel Schwefel war an den Kraterwänden abgesetzt. Am Boden des Kraters M lag ein See mit grünem Wasser, auf dessen Spiegel ein gelblicher Schwefelschaum schwamm (2, 10).

Guadeloupe

In der Nacht vom 19. zum 20. Oktober 1956 hatte die Soufrière auf der Insel Guadeloupe (Kl. Antillen) eine heftige Explosion mit Förderung von grauer Asche und grosser Mengen Schwefelgase. Ein weiterer Ausbruch mit stärkerem Aschenregen folgte am Abend des 24. Oktober. Den Ausbrüchen war eine Temperaturerhöhung der Fumarolen und die Bildung neuer Fumarolen vorangegangen, ferner eine Bebenserie, die sich im Dezember wiederholte. Die Explosionen bildeten eine Spalte auf dem Gipfel des alten Lavadoms, von der später grosse Mengen weissen Dampfes aufstiegen (8, 9, 67).

Llascar

Der 5990 m hohe Llascar (Toconado) in der Puna de Atacama, zuletzt 1951-52 tätig, hatte im Juni und Juli 1954 eine weitere Ausbruchsperiode (51).

Llaima

Der basaltische Llaima (3082 m) in den südchilenischen Anden war 1955 eruptiv tätig und nach einem Jahr der Ruhe wieder im November 1956: Lavaströme flossen an den Flanken herab (67).

Nilahue

Im Juli 1955 entstand in dem Vulkangebiet an den Seen

Ranco und Puyehue im südlichen Chile, welches ich früher im Bulletin volcanologique kurz skizziert habe (26), unter starken Explosiverscheinungen 5 km nördlich vom Vulkan Riñináhue ein neuer Krater, der in den verschiedenen Berichten teils Nilahue (weil nahe dem Nilahue-Fluss gelegen), teils Carran genannt wird. Die erste Explosion erfolgte am 26. Juli in einem Weideland, sie warf nur Oberflächengestein aus und war von starker Lufterschütterung und pochenden Getösen begleitet. Dann folgten 22 Stunden lang Erdbeben und erst am 27. nachmittags begann der eigentliche Ausbruch mit einem ungeheuren Knall, eine schwarzgraue bis schwefelgelbe, von elektrischen Entladungen erleuchtete Rauchsäule erhob sich 10000 m hoch und nahm dann Piniengestalt an, grosse Gesteinsbrocken wurden 6 km weit geworfen, der Lapillifall reichte 35 km weit und der lange anhaltende Aschenregen erreichte Osorno, Temuco und Valdivia. Nahe dem Vulkan wurde die Aschenlage 1 m hoch, Blockhütten stürzten ein; diese Haupttätigkeit dauerte 150 Stunden. Am 1. August noch 5000 m hohe Aschensäule, auch der Auswurf weissglühender Lavablöcke wird erwähnt. Bäche wurden gestaut und zwei Personen durch Gase getötet. Die Explosionen wiederholten sich dann drei Monate lang, wobei ihre Stärke langsam abnahm. Nach mehreren Tagen Ruhe fanden immer wieder heftige Aschenausbrüche statt, wobei auch Lapilli zu bedeutender Höhe emporgeschleudert wurden, ferner vom Schlot mitgerissene Bruchstücke und frische Bimssteine eines sauren Magmas. Der feine Aschenregen reichte 800 km weit nach N bis Santiago, es wurden etwa 300 Mill. m^3 altes und neues Material ausgeworfen. Der neue Explosionskrater hat einen Durchmesser von 1500 × 1200 m, er liegt in hügliger Gegend nahe zwei älteren Maaren und war sein Kegelbau von nur geringer Höhe. Im Dezember 1955 war der Krater schon völlig ruhig und es hatte sich auf seinem Boden bereits ein See angesammelt. Sehr zweifelhaft sind Berichte über eine gleichzeitige Tätigkeit der Vulkane Choschuenco und Riñináhue (21, 42, 67).

PAZIFISCHER OZEAN

Boquerón 14,1-2

Der 1952 entstandene Vulkan Boquerón oder, wie er neuerdings genannt wird, Bárcena, auf der Insel San Benedicto (s. 27, p. 84-86) ist nach 1953 ruhig geblieben und beschränkte seine Tätigkeit auf Dampfaushauchungen, 1954 erloschen einige grosse Kraterfumarolen. Die neue Lava ist nach Richards trachyandesitisch oder andesitisch (49, 50).

Isabela

Die grösste der Galapagos Inseln, Isabela (Albemarle), besteht aus fünf basaltischen Schildvulkanen mit grossen Gipfelcalderen und etwa 2500 Satelliten (Schweiss- und Lockerschlackenkegeln, Tuff-und Aschenkegeln, Spratzkegeln etc.), meist in Gruppen oder entlang Spalten angeordnet; ausser Lavaströmen finden sich auch Tufflagen und zahlreiche konzentrische und radiale Spalten, die Gesteine sind Plagioklasbasalte mit 47-48 % SiO_2.

Der Vulkan *Wolf* (5600 f nach Lit. 7), am Nordende der halbmondförmigen Insel gelegen, hat eine Gipfelcaldera von 7 km Durchmesser, letzte Ausbrüche 1925 und 1948, er zeigte im Frühjahr 1953 eine leichte Solfatarentätigkeit.

Darwin, 4300 f, folgt nach S auf den Wolf, seine Gipfelcaldera hat ebenfalls 7 km Durchmesser, Ausbrüche sind nicht bekannt, 1953 wurden auch keine Solfataren gefunden, aber noch sehr frische Lavafelder.

Alcedo, 3650 f, südlich vom Darwin, ist der niedrigste der Vulkane auf Isabela, hat aber die grösste Caldera von 10 km Durchmesser, 1953 Solfatarentätigkeit. Am 9. November 1954 begann ein Ausbruch des Alcedo in der Caldera und in Spalten an der Ostflanke, später floss Lava nach NNW ab. Dem Ausbruch sind Hebungen am Westfuss des Vulkans vorangegangen.

Sierra Negra (Volcan Grande), 4890 f, in Südteil der Insel gelegen, ist nicht der höchste, aber der mächtigste Vulkanberg auf Isabela, seine Gipfelcaldera hat 9 ½ km

Durchmesser und eine geringe Tiefe (ca. 120 m), letzte Ausbrüche 1948 und 1953-54. Ein starker Flankenausbruch begann am 27. August 1953 an der Nordseite mit dem Aufreissen einer 3 km langen Spalte und 10000 m hoher heller Dampfsäule. Am 31. VIII. warf die Spalte alle 7 - 8 Minuten Glutfontänen empor, die ausfliessende Lava verzweigte sich und erreichte in mehreren Zungen später die Küste an der NW-Seite. Die Tätigkeit dauerte wahrscheinlich bis Januar 1954.

Dicht westlich der Sierra Negra liegt der *Cerro Azul*, 5540 f, der steilste Kegel auf Isabela, mit ovalem Gipfelkrater von 1½×4½ km Durchmesser, letzte Ausbrüche 1949 und 1951; 1953 zeigte er nur eine schwache Fumarolentätigkeit (7, 48, 49, 62).

Mauna Loa 13,2-2

Der Mauna Loa auf Hawaii ist 1954-56 ruhig geblieben, abgesehen von gelegentlichen örtlichen Beben (62, 63).

Kilauea 13,2 - 3

Nach 18 ½ Monaten Ruhe begann am Morgen des 31. Mai 1954 nach schwacher Bebenvorbereitung ein kurzer Ausbruch des Kilauea auf Hawaii. Zuerst erschienen bis 200 m hohe Lavafontänen im Schacht Halemaumau, die Dampfsäule stieg 10000 m hoch; kurz danach brach nordöstlich ausserhalb des Halemaumau auf dem Calderaboden des Kilauea ebenfalls Lava aus. Eine gebrochene SW-NO-Spalte war innerhalb und ausserhalb des Schachtes tätig, auf der mehrere kurze Fontänenreihen eine orangegelb leuchtende Lava förderten, die sich schnell mit einer dunklen Erkaltungskruste bedeckte und den ganzen Boden des Halemaumau — also die Lava von 1952 — überfloss. Ein etwa gleichgrosses Lavafeld entstand auf dem Calderaboden im NO. Fontänenhöhe und Spratzkegelbildung blieben gering und schon am 3. Juni nachmittags war die Eruption beendet. Die meiste Lava wurde in den ersten zwei Stunden gefördert, ihre Oberfläche fast überall Pahoehoe, Volumen etwa 16 ½ Mill. Kubik-Yards.

Am 28. Februar 1955 8.00 begann nach Bebenvorbereitung ein Flankenausbruch an der Ostseite des Kilauea mit Spaltenbildungen nahe einem älteren Schlackenkegel, die Lavafontänen stiegen 20 - 50 m hoch und die Lavabäche nahmen ihren Weg nach S. Nach und nach entstanden weitere Spalten mit Fontänen und Spratzkegeln, während die zuerst entstandenen ihre Tätigkeit auf Dampfabgabe beschränkten, dabei war die seismische Unruhe anhaltend. Diese Ausbrüche dauerten intermittierend bis zum 26. Mai, wobei das Ausbruchszentrum in Richtung auf die Kilauea-Caldera hin wanderte. Die Schlackenkegelbildung blieb gering, ein Teil der Ortschaft Kapoho wurde zerstört, mehrere Lavazungen erreichten die Südküste. Die Förderung war ein dünnflüssiger Plagioklasbasalt mit 50.53 bis 51.24% SiO_2, Volumen: 120 Mill. Kubik-Yards (32, 33, 62).

Unterseevulkane in den Hawaii - Inseln

Am 20. August 1955 war ein submariner Vulkan zwischen den Inseln Nihoa und Nekker in der westlichen Hawaii-Gruppe tätig. Flieger beobachteten eine aufgeregte und dampfende Meeresfläche von ovalem Umriss und ca. 1500 m Durchmesser mit gelblichem Wasser und schwimmenden Bimsteinbarren. Am folgenden Tage waren diese Erscheinungen verschwunden, aber das Meerwasser noch getrübt und Serien von Flutwellen gingen nach allen Seiten aus. Am 22. September stieg hier Rauch vom Meeresspiegel auf, der braune und gelbe Streifen zeigte (62, 67).

Ein weiterer submariner Ausbruch erfolgte am 23. Mai 1956 zwischen den Inseln Kauai und Oahu, Einzelheiten werden nicht berichtet (67).

Tongariro

Der in der Tagespresse berichtete Ausbruch des Tongariro auf Neuseeland in Januar 1954 hat nicht stattgefunden, wie mir Herr Gregg in Rotorua mitteilte. Offenbar haben Buschbrände die Veranlassung zu der irrtümlichen Mitteilung gegeben (1, 67).

Ngauruhoe

Nach 9 Monaten Ruhe begann am 13. Mai 1954 eine neue Tätigkeitsperiode des Ngauruhoe (2333 m) auf Neuseeland mit dem Ausbruch einer 4000 m hohen Aschensäule, bis Ende Mai folgten dann weitere ähnliche Explosionen mit Gluterscheinungen aus dem Zentralkegel am Westrand des grossen Gipfelkraters. Anfang Juni wurden Schlackenfontänen beobachtet und vom 4. Juni bis 26. September flossen 10 Lavaströme, teils nebeneinander, teils übereinander auf die W- und NW-Flanke, der bedeutendste am 30. Juni, sie waren zum Teil von heissen Absturzlawinen begleitet. Währenddem wurde der Zentralkegel durch die anhaltenden Schlackenauswürfe bedeutend vergrössert, sein westlicher Kraterrand aber durch die Lavaergüsse aufgerissen. Die Förderung war ein dunkelgrauer bis schwarzer Andesit. Die Mächtigkeit der Blocklavaströme schwankte zwischen 3 und 10 m, ihre Länge zwischen 300 und 2000 m, das Volumen schätzt Gregg auf 8 Mill. Kubik-Yards. Erst im September traten neben den Lavaergüssen und Schlackenfontänen wieder lautstarke Aschenexplosionen mit Lufterschütterungen auf, im letzten Quartal 1954 wurde die Tätigkeit dann schwächer. Im Dezember war der Zentralkegel schon fast genau so hoch wie der höchste Punkt des alten Kraterrandes im O.

Vom 2. Januar bis 13. März 1955 fanden noch mehrere Explosivausbrüche mit Schlacken-, Lapilli- und Aschenauswurf statt, begleitet von Gluterscheinungen, Getösen und der Emission blauer Gase. Bis Juni war noch Lava im Krater anwesend, weitere Explosionen am 19. und 21. VI: im Juli dann Zurücksinken der Lavasäule und Zunahme der Kratertiefe. Im Dezember wurde erneut Glutschein und zunehmende Fumarolentätigkeit beobachtet.

Am 11. Januar 1956 wieder Glutschein und bedeutende Dampfemission mit blauen Schwefelgasen und vom 12. - 22.

Januar folgte eine Serie von Explosionen mit dem Auswurf von reichlich Asche und Glutmaterial, die Aschenlage am Gipfel wurde bis 1 m dick. Am 10. und 11. Februar war der Ngauruhoe nochmals explosiv tätig und kehrte dann zum Fumarolenstadium zurück (1, 23, 24).

Ruapehu

Der Ruapehu (2803 m) auf Neuseeland ist während der Berichtszeit ruhig geblieben, aber Anfang Oktober 1954 war seine Dampfemission so bedeutend, dass am 8. X. der ganze Kratersee mit Dampf bedeckt war (62).

Lamington 5,3 - 1

1954-1956 ist der seit 1951 tätige Lavadom des Lamington (1780 m) auf Neu Guinea weiter gewachsen und erreichte eine Höhe von 560 m über dem Kraterboden. Explosivausbrüche fanden nicht mehr statt, aber häufige Gipfelabstürze. Die Domlava ist ein Hornblende-Andesit mit 58.45-60.32% SiO_2 (16).

Langila 5,2 - 1

Der Langila (Nangila, 1189 m) am Westende der Insel Neu Britannien hatte
1954 vom 18. Mai bis 5. Juni, 2. Juli bis 12. September und 1. Oktober bis 13. November,
1955 am 15., 16., und 17. Februar und 1., 6., und 16. Juni,
1956 vom 25. bis Ende März
Explosivausbrüche von wechselnder Stärke aus seinem nördlichen Krater mit Auswürfen von Aschen und Lapilli, die Förderung ist ein Augit-Hypersthen-Andesit. Die stärkste Tätigkeit war am 23. Juli 1954 mit 4000 m hohen Aschensäulen, lauten Getösen, elektrischen Entladungen und Schwefeldunst (16, 68).

Long 5,1 - 5

Der vom 8. Mai 1953 bis 7. Januar 1954 tätige Zentralkegel im Kratersee der Long-Caldera hatte vom 5. -13. Juni

1955 eine weitere Ausbruchsperiode mit dem Auswurf glühender Aschen (16, 55).

Bam 5,1 - 1

Der Inselvulkan Bam (Biem, 600 m) vor der Nordküste von Neu Guinea hatte während der Berichtszeit leichte Explosivausbrüche am 3. August, 6. Oktober und im November 1954, 3. und 7. Juni, 14. und 26. November, 2.-8. und 31. Dezember 1955 und am 1. und 2. Januar 1956 (16).

Tuluman 5,0 - 1

Tuluman ist ein submariner Vulkan zwischen den Inseln Lou und Baluan in der Admiralitätsgruppe. Hier waren vom 27. Juni 1953 bis 25. November 1955 6 Eruptionszentren tätig, welche ausser Explosivausbrüchen auch Lavaextrusionen zeigten. 4 Krater tauchten aus dem Meer und vereinigten sich zu 2 Inseln, deren grössere im Juli 1955 40 m hoch war, die beiden anderen blieben unter dem Meeresspiegel (16, 55, 69).

Unterseevulkan im westlichen Pazifik

Im Oktober 1955 wurde 600 ml (Sml?) östlich der Nordspitze von Luzon ein submariner Vulkan tätig: eine kochende Meeresfläche wurde beobachtet, Position etwa 19°N und 132° 15′ O. Hier oder in der Nähe hat 1854 ein submariner Ausbruch stattgefunden (62).

Myojin

Die letzte Lavadominsel des Myojin ist im August und September 1953 durch Explosionen zerstört worden (s. 27, p. 92-94) und nicht wieder aufgetaucht. Im Oktober fand man die Anzeichen einer submarinen Bank, der Vulkan blieb dann ruhig. Erst am 4. November um 14.00 und 15.00, am 5. November 1954 und am 25. Juni 1955 wurden hier wieder submarine Ausbrüche gesehen (14, 39, 41).

Minami Iwo Jima

Anfang Februar 1954 war nahe der Insel Minami Iwo Jima ein Unterseevulkan tätig: Die Meeresoberfläche war kochend und dampfend, zu einer Inselbildung (wie zuletzt 1914) kam es aber nicht. Am 31 Januar hatte hier ein starkes Seebeben stattgefunden (62).

OSTASIEN

Schewelutsch 10,0 - 27

Der nördlichste tätige Vulkan auf Kamtschatka, der 3335 m hohe Schewelutsch, hatte seine letzte Tätigkeitsperiode vom 5. November 1944 bis 6. April 1950. Dabei bildete sich zuerst am Ostende einer z. T. in historischer Zeit entstandenen Quellkuppenreihe ein Explosionskrater, in dem 1946-49 eine neue Kuppe — Sujelitsch — aufgestaut wurde. Dabei traten bis 8 km lange Glutwolken auf und bis 100 m hohe Felsnadeln wurden aus dem Domgipfel ausgepresst, die immer wieder abstürzten. Der Dom wurde 200 m hoch, sein Gestein ist ein Hornblende-Andesit mit 59.57 % SiO_2. Zum Abschluss der Tätigkeit wurden aus dem Kuppengipfel mehrere steilwandige Explosionskrater ausgesprengt. In der Berichtszeit ist der Vulkan ruhig geblieben, aber die Fumarolentätigkeit auf dem neuen Dom war anhaltend stark (36, 46).

Kliutschewskoy 10,0 - 26

Der Kliutschewskoy (4850 m) auf Kamtschatka blieb nach seinem grossen Ausbruch 1944-45 (s. 47) relativ ruhig, abgesehen von zeitweise sehr kräftiger Fumarolentätigkeit. Im Oktober 1946, November 1951 und Juni 1953 entstanden neue Satelliten an der Ostflanke, Aschenausbrüche des Gipfelkraters waren im Mai 1949, November 1951 und Juni 1953.

Am 28. Mai 1954 begann eine neue Periode starker Explosionen des Gipfelkraters, sie waren bis zum 6. Juni strombolianisch: Dampf-und Lapilliauswürfe unter Glutschein, glühende Bomben wurden bis 400 m hoch geworfen, die tätige

Bocca lag im östlichen Teil des Kraters. Vom 7. Juni an traten immer häufiger auch Aschenwolken auf, zeitweise folgten sich die Explosionen in Abständen von 1 bis 2 Minuten und trieben schwarze Säulen bis 2000 m hoch. Zuweilen wurden auch Rauchringe beobachtet und anscheinend waren jetzt drei Bocchen nebeneinander auf einer Spalte tätig. Währenddem war die seismische Unruhe nur schwach. Die Tätigkeit dauerte im September noch an, aber die Pausen zwischen den Explosionen wurden länger: 2 bis 30 Minuten. Auch war jetzt kein Glutschein mehr zu sehen. Die Förderung war ein Plagioklasbasalt mit 52.67 % SiO_2 (46, 60).

Vom 27. Juli bis 2. August 1956 Ascheneruptionen des Gipfelkraters; gleichzeitig entstanden im Verlauf der bei dem Flankenausbruch 1945 aufgerissenen Radialspalte im SO zwei weitere Satelliten, Bernadskogo und Kryschanowskogo mit resp. 500 m und 1000 m langen Lavaströmen (60).

Besymjannaja 10,0 - 25

Nach starker Bebenvorbereitung ist der 3085 m hohe Vulkan Besymjannaja in der Kliutschewskoy-Gruppe (Kamtschatka) erstmals in historischer Zeit in Tätigkeit getreten. Die Ausbrüche begannen am 22. Oktober 1955 und schon am ersten Tage erreichte die von elektrischen Entladungen erleuchtete Aschensäule eine Höhe von 5000 m über dem Krater, hellgraue Asche fiel bis zur Ostküste, dabei dröhnende Getöse und anhaltende seismische Unruhe. Im November weitere starke Explosivausbrüche mit weitreichenden Aschenfällen, am 8. XI. sah man zuerst Glut über dem Krater, die Maximaltätigkeit war vom 13. bis 18. November mit bis 11000 m hohen Aschensäulen voller elektrischer Entladungen, in 40 km Entfernung (in Kliutschi) wurde die Aschenlage 2 cm hoch. Im Dezember wechselnd starke Tätigkeit und im Januar 1956 waren die begleitenden seismischen Störungen bedeutend : Pro Tag waren es oft 400 Erdstösse, insgesamt seit Oktober 1955 30000. Der Gipfel war jetzt teilweise zerstört und der neue Krater beträchtlich breiter geworden, in seinem Innern stieg ein Lavadom auf, dessen halb erstarrte Kruste in dunkelroter Glut leuchtete. Mitte Februar hatte der Gipfel des Lavadoms den Kraterrand erreicht und bröckelte über diesen ab, Lavalawinen traten auf.

Am 30. März 1956 erfolgte ein gewaltiger Explosivausbruch der Besymjannaja, sehr ähnlich dem des Katmai 1912. Die von elektrischen Entladungen erleuchtete Aschensäule stieg über 45000 m hoch und die Lufterschütterungen waren weithin wahrzunehmen. Die den Vulkan umgebende Landschaft wurde völlig verändert, der halbkugelförmige Lavadom und die ganze Südostseite des Gipfels weggesprengt und ein Krater von 1500 × 2000 m Durchmesser und 1000 m Tiefe geschaffen. Das Auswurfsmaterial — glühende Aschen und Agglomerate — wurde nicht nur hoch in die Luft geschleudert, sondern ergoss sich auch in Kaskaden (Glutwolken?) über die Flanken, besonders nach der Ostseite, schmolz den Eis- und Firnmantel des Vulkans rapide und verursachte dünnflüssige Schlammfluten, die 75 km weit durch das Bett des Chapitza-Flusses bis in den Kamtschatkafluss strömten. Am Ostfuss der Besymjannaja entstand eine Ablagerung ähnlich dem Tal der 10000 Dämpfe in Alaska. Ein starker Aschenregen fiel 400 km weit nach NO und von dieser Explosion stammen vermutlich auch die Feinaschen, die man am 3. und 4. April in der Stratosphäre über West-England feststellte. Im Frühsommer 1956 neue Tätigkeit in dem Explosionskrater: Dampfwolken und gelegentliche Aschenfälle, am Kraterboden begann ein neuer Lavadom aufzusteigen (6, 22, 30, 60, 64, 67).

Tolbatscha 10,0-24

Die Tolbatscha (3085 m) in der Kliutschewskoy Gruppe auf Kamtschatka war 1954 stark dampfend und hatte am 21. Februar, 22., 24., und 26. März und 13. Juni Aschenausbrüche, Glutschein wurde nicht gesehen. Am 28. August fand B. J. Piip am Gipfel eine frische Aschenlage, die z. T. aus Glasfäden (Peles Haar) bestand. Der Kraterboden war stark von Spalten durchsetzt und der tätige Schacht erschien gegenüber dem Zustand 1941 grösser und tiefer, zur Zeit wurden nur Wasserdämpfe und nach SO_2 riechende Gase gefördert (46).

Karymskaja 10,0 - 13

Gleich nach dem schweren Kamtschatkabeben vom 5. November 1952 erneuerte der Vulkan Karymskaja (1486 m, Mittel-Kamtschatka) seine Tätigkeit und hatte 1952 und 1953 mehrere Aschenausbrüche und weitere werden für 1955 angegeben (60).

Schupanowskij 10,0 - 12

Der Schupanowskij-Vulkan auf Kamtschatka (2958 m) hatte im Dezember 1956 schwache Aschenauswürfe (60).

Pik Sarytschewa 9 - 24

Der Pik Sarytschewa (1497 m) auf der Kurileninsel Matua hatte nach acht Jahren Ruhe vom August bis Oktober 1954 eine neue Ausbruchsperiode, die aber nicht die Stärke derjenigen vom November 1946 erreichte: die Lavasäule stieg bis zum Kratergrund empor und bildete hier eine flache Kuppel mit starker Fumarolentätigkeit, von Zeit zu Zeit fanden leichte Aschenausbrüche statt. Auf den Agglomeratströmen der Eruption von 1946 waren noch sekundäre Fumarolen tätig (60).

Meakan

Am 19. November 1955 hatte der Meakan auf der Insel Hokkaido einen leichten Explosivausbruch (62).

Asamayama

Über die Tätigkeit des Asamayama (2554 m) bis Mai 1954 hat T. Minakami hier bereits berichtet (39). Weitere leichte Aschenausbrüche folgten vom Juni bis 6. September und am 2. und 4. November 1954. Am 11. Juni 1955 7.46 wieder Explosivausbruch von drei Minuten Dauer mit laut rollendem Getöse und Aschenfall in der Umgebung; im Dezember 1955 war der Vulkan wieder explosiv tätig (18, 40, 62).

Miharayama

Über den Ausbruch des Miharayama auf der Insel Oshima 1953-54 hat T. MINAKAMI bereits hier berichtet (39), weitere Literatur s. Nr. 18. 19 und 57. Im Dezember 1955, Januar und August 1956 war der Vulkan wieder leicht explosiv tätig, ohne dass Lava floss (61, 67).

Asoyama

Am 24. Juli 1955 war der Zentralkegel Nakadake in der Aso-Caldera strombolianisch tätig und warf glühende Bomben bis 300 m über den Kraterrand empor (62).

Sakurajima

Vom 13. bis 31. Oktober 1955 hatte der Sakurajima (1118 m) 18 Explosivausbrüche, deren Aschenpinien bis 2500 m hoch stiegen, dabei Lufterschütterungen, elektrische Entladungen und Blockauswürfe, folgend ausgedehnte Aschenfälle. Vorangegangen war diese Eruptionsperiode von Mikrobeben und zunehmender Fumarolentätigkeit. Seit der grossen Eruption von 1914 ist das Eruptionszentrum bei zahlreichen kleineren Ausbrüchen von 1935 bis 1950 bergaufwärts gewandert und lag 1955 im Nordteil des tätigen Südkraters Minamidake, hier entstand ein Explosionskrater von 110 m Durchmesser. Diese Periode förderte aber noch kein frisches Material, die erste Explosion am 13. X. warf 55000 m^3 Schutt aus.

Nach 66 Tagen relativer Ruhe nahm der Vulkan seine Tätigkeit am 6. Januar 1956 wieder auf und folgten bis Ende Mai mindestens 50 Ausbrüche von grösserer Stärke als im Oktober 1955. Jetzt wurden Lavablöcke, Brotkrustenbomben und Bimssteine von frischem Material gefördert, die Blöcke wurden bis 1000 m weit geschleudert. Zu einem Lavaerguss kam es nicht (54, 56).

Suwanose

Die Vulkaninsel Suwanose-Jima in der Tokara-Gruppe der Riu-Kiu-Reihe ist ein 799 m hoher Calderavulkan mit mehreren Kratern, deren jüngster seit September 1949 in ständiger Tätigkeit ist. Ausser Gasen werden Aschen, Lapilli und Lavablöcke ausgeworfen, die Förderung ist ein Augit-Hypersthen-Andesit mit 54.73 bis 55.94 % SiO_2 (Oktober 1953). Am 22. Februar 1954 um 12.30 fand ein besonders starker Aschenausbruch statt, im Mai '54 war die Tätigkeit noch anhaltend (44).

Taal 7,3 - 7

Die Solfatarentätigkeit im Taalkrater hat sich Anfang 1954 weiter verstärkt und war jetzt die Dampfförderung doppelt so stark wie im Mai 1953 (31).

Hibok Hibok 7,1 - 8

Nach seiner Ausbruchsperiode 1948-53 beschränkt sich die Tätigkeit des Hibok Hibok auf ruhige Dampfabgabe. 1954 lösten starke Regenfälle in der frischen Aschenlage Schlammströme aus und vom 2.-5. Februar 1956 wurden 26 vulkanische Beben aufgezeichnet (67).

Makaturing 7,1 - 4

Das starke tektonische Beben am 1. April 1955 im W-Teil der Insel Mindanao verursachte Erdrutsche an den Flanken des Macaturing, die Meldungen über einen Ausbruch des Vulkans entsprechen nicht den Tatsachen (62).

Celebessee 6,7 - 5

Am 13. Februar 1955 hatte der in grosser Tiefe gelegene zuletzt 1922 tätige Unterseevulkan in der Celebessee Ausbrüche, deren Dampf- und Aschenwolken sich bis 300 m über den Meeresspiegel erhoben (62).

Merapi (Java) 6,3 - 25

Von den zahlreichen Vulkanen Indonesiens liegen nur einige dürftige Nachrichten über die Tätigkeit des Merapi auf

Java vor. Am 18. Januar 1954 hatte der Vulkan nach vorangegangenen Beben einen heftigen Ausbruch mit bedeutenden Glutwolken und Lavaerguss. 68 Personen wurden getötet. Am 26. Januar Aschenregen bis Semarang, am 30. I. neuer starker Explosivausbruch mit hoher Rauchsäule und Lavaförderung. Anfang Februar traten Lahars auf. Nach dieser Ausbruchsperiode war der Gipfel durch Lavaaufstau sehr spitz und an 3000 m hoch geworden (1943: 2911 m).

Mitte August 1955 begann eine neue Ausbruchsperiode, die sich in Oktober und Dezember verstärkte: Glutwolken, Lavaerguss und seismische Unruhe. Am 3. Januar 1956, 6.30 plötzlicher bedeutender Explosivausbruch mit Glutwolken, weitreichenden Aschenfällen und dem Auswurf glühender Lavablöcke, Aschenfinsternis in Magelang und Salatiga, die Bebenbegleitung war schwach. Am 9. Januar dauerten die Ausbrüche noch an und waren jetzt nach NO gerichtet, am Fuss des Merapi wurde die Aschenlage bis 5 cm dick (67).

ANTARKTIS

Mehrere Bilder aus dem Jahre 1955 zeigen den *Erebus* (4077 m) teils leicht dampfend, teils mit bedeutender Dampffahne und auf einem weiteren ist die obere Hälfte des Kegels mit einer frischen Aschenkappe bedeckt. 1956 wurden periodisch grosse dichte Dampfballen ausgestossen, aber kein Aschenfall, vom Flugzeug aus sah man den Krater steilwandig und sehr tief (53, 67).

SULLIVAN (53) nennt ausserdem den *Sawadowsky* in der Süd-Sandwich-Gruppe einen eruptiv tätigen Vulkan, gibt aber kein Datum an. 1908 sah man auf der Sawadowsky-Insel Solfataren mit fliessendem Schwefel.

AFRIKA

Oldonjo L'Engai 2,2 - 12

Ende Juli 1954 begann eine neue Ausbruchsperiode des Oldonjo L'Engai in Tanganjika, wobei reichlich helle Asche ausgeworfen wurde. N. J. Guest hat den Vulkan mehrmals bestiegen und fand im August reichlich Natron-Absätze am Gipfel. Am Boden des Nordkraters lag ein niedriger Aschenkegel, der periodisch mit rollendem Getöse und Gluterscheinungen Asche und Lavablöcke auswarf. Die Fumarolentätigkeit im Krater verstärkte sich nach Regenfällen. Ende September war der Zentralkegelkrater erweitert, die ausströmenden Gase rochen nach SO_2 und H_2S. Im Dezember wurden mehr Wasserdämpfe und weniger Schwefelgase gefördert. Die Ascheneruptionen dauerten bis zum 20. Januar 1955 (25, 45).

Nijragongo 2,3-3

Der Nijragongo in der Virunga-Gruppe war 1954 und 1955 stets tätig und der Glutschein seines Lavasees weithin sichtbar. Am 10. September wurde er von A. Heim bestiegen. Auf dem ebenen Kraterboden lag ein 200 m tiefer Einsturzschacht mit senkrechten Wänden und auf dessen Boden ein 400 × 200 m grosser kochender Lavasee. Alle 2-5 Minuten erfolgten hieraus Explosionen weisser Schwefeldampfballen, die dann einen langen Schweif nach W hin bilden (28).

Nyamlagira 2,3-2

Am 20. Februar 1954 entstand am Südfuss des Nyamlagira (Nyamuragira) nördlich vom Kivusee unter starken Beben der Satellit Mihaga. Sein Ausbruch dauerte bis zum 21. Mai, er bildete einen 80 m hohen Kegel und ergoss einen 15 km langen Lavastrom nach NO, der im August oberflächlich schon erkaltet war. In der Gipfelcaldera war währenddem nur ein Solfatarenfeld mit Temperaturen bis 200° C unter der Ostwand tätig (28, 67).

Cameroon 2,4-1

Im Juli 1954 hatte der Vulkan einen Explosivausbruch mit hohen Rauchsäulen, dem mehrere Beben vorangingen; kein Lavaerguss, die Förderung war basaltisch (67).

ATLANTISCHE INSELN

Vatna-Jökull

1954 und 1955 waren die subglazialen Vulkane unter dem Eisfeld des Vatna-Jökull sehr unruhig. Schon im Januar 1954 wurde Tätigkeit beobachtet und am 14. Juli begann ein Gletscherlauf vom westlichen Randgletscher Skeidarar-Jökull, der sein Maximum am 18. VII. erreichte, als 10 Abflusskanäle tätig waren. Die ausgeflossene Wassermenge wird auf 3 km^3 geschätzt. Vom Flugzeug aus wurde in oder nahe der Grimsvötn-Caldera eine dampfende Krateröffnung im Eis beobachtet, in deren Umgebung die Eisfläche stark zerklüftet war. Mehrere Tage später wurde über Island ein intensiver Schwefelgeruch wahrgenommen. Ende Juli hatte dann der Fluss Skeidara wieder die normale Wassermenge. Da von Aschenfällen nichts berichtet wird, hat wahrscheinlich ein subglazialer Lavaerguss stattgefunden.

Im Juni 1955 kurzer Ausbruch an einer anderen Stelle (Position nicht angegeben) mit hoher Feuersäule und einem Gletscherlauf, der innerhalb zwei Stunden 100 Mill. m^3 Wasser ins Meer führte. Diese Eruption hinterliess einen flachen Krater von 2000 m Durchmesser und 100 m Tiefe in der Eisdecke, dessen Eiswände von zahlreichen konzentrischen Spalten zerrissen waren, am Boden lag ein kleiner dampfender See. Am 4. September Ausbruch eines Kraters 42 km nördlich vom Südrand des Vatna-Jökull, Schwefelgeruch in Süd-Island und Gletscherlauf mit gelbem, nach Schwefel riechendem Wasser im Bereich des Flusses Skaftau am Westrand des Vatna-Jökull (5, 65, 67).

EUROPA

Ätna

1954 war der Nordostkrater des Ätna stets dampfend und oft dumpfe Knalle aus der Tiefe zu hören, Ende Dezember erhöhte Tätigkeit.

Im Mai 1955 begann die Lavasäule wieder zu steigen, die Explosionen des NO-Kraters wurden häufiger und die Dampfwolken zeigten Glutreflexe. Am Abend des 29. Juni begannen Schlackenauswürfe und am 30. stand die Lavasäule schon 30 m unter der Rand der Kraterterrasse. Im Juli war diese Tätigkeit anhaltend, dabei wurde auf dem Kraterboden ein Lockerschlackenkegel aufgebaut, der am 12. VII. 20 m hoch war. Am 4. Juli folgten sich die Explosionen mit dröhnendem Getöse alle 2-3 Sekunden, am 7. stiegen Lapillisäulen 700 m empor und am 8. erfolgte der erste kleine Lavaerguss aus einer Spalte an der Nordseite des Schlackenkegels. Am 18. Juli floss ein grösserer Strom nach O in das Valle di Leone, der nach 7 Tagen 3 km lang war. Später fanden weitere kleine Lavaergüsse statt, meist in nördlicher Richtung. Im August und September war die Zahl der Explosionen in jeder Minute etwa 40, Schlacken wurden dabei 300 m hoch geworfen. Der Schlackenkegel wurde 90 m hoch, vorübergehend war eine zweite Bocca an seiner Flanke tätig. In der zweiten Hälfte des September liess die Tätigkeit hier nach und dafür hatte der Zentralkrater des Ätna vom 22.-24. IX. einen kurzen, aber heftigen Ausbruch aus dem im Oktober 1945 entstandenen Einsturzschacht. Hier wurde ein 60 m hoher Schlackenkegel aufgeschüttet und ein kurzer Lavastrom auf den Kraterboden ergossen, der auch die 1949 aufgerissene Spalte zum Teil ausfüllte. Nachdem verstärkte sich die Tätigkeit des NO-Kraters wieder und traten auch kurze Lavazungen aus. Im November wurden alle 3-4 Minuten Lavablöcke und Aschen ausgeworfen, aber späterhin wurden die Pausen zwischen den einzelnen Explosionen wieder länger und dauerten oft mehrere Tage. Die basaltische Förderung hatte ein Volumen von 3.715.000 m^3 (13, 29).

Am 28. Februar 1956 begann eine neue Ausbruchsperiode des Ätna, über die bisher nur Mitteilungen aus der Tagespresse vorliegen. Schwarze Rauchsäulen erschienen über dem Zentralkrater und den Donner der Explosionen hörte man bis Zafferana. Am 29. II. folgten sich die Ausbrüche alle 2-3 Sekunden. Am 2. März Aschenfall bis Catania, ein 150 m breiter Lavastrom floss aus und verzweigte sich mehrmals. Nahe dem Ausbruchsapparat vom November 1928 war eine neue Flankenspalte mit 7 Kratern tätig. Ab 6. März liess der Ausbruch an Heftigkeit nach, aber schon am 4. April floss wieder Lava aus dem NO-Krater, Aschenfälle und Glutschein. Am 5. April folgten sich die Explosionen alle 4-5 Minuten, sie warfen Gase, Asche und Bomben aus. Ein Lavastrom war am 7. IV. noch fliessend und verzweigte sich ebenfalls. Nach einer Pressenotiz vom 16. April soll der Ätna um 32 m an Höhe zugenommen haben und betrug die absolute Höhe jetzt 3295 m. In der Nacht vom 10. zum 11. September warf der Vulkan wieder dichte dunkle Rauchwolken aus (67).

Stromboli

1954 hatte der Stromboli ausser seiner gewöhnlichen Tätigkeit einen Effusivausbruch vom 1. Februar bis 13. März, der Lavastrom floss an der Nordseite der Sciara del Fuoco und ergoss sich 150 m breit ins Meer; Begleitbeben fehlten. Am 6. Dezember fand ein stärkerer Aschenausbruch mit Getöse statt und wieder floss Lava nach NW ab. Am 23. Dezember begann eine langanhaltende Bebenserie in den Liparischen Inseln, die am 27. und 28. besonders stark auf Salina spürbar war. Am Morgen des 29. ergoss sich aus drei Quellen ein dünnflüssiger Lavastrom über die Sciara, Aschenregen fielen über die ganze Insel und am 30. XII. zeigte der Vulkan einen langen graugelben Dampfschweif.

Im Januar und Februar 1955 war die Tätigkeit wiederholt von Gluterscheinungen begleitet und am 28. Februar erfolgte ein Lavaausbruch an der submarinen Sciara-Flanke wenig unter dem Meeresspiegel, vermutlich aus einer Spalte, welche die grosse Explosion vom 11. September 1930 geöffnet hatte. Die Lavamassen stauten sich hier, sodass am 3. März eine neue Insel auftauchte, die sich bis zum 12. III. vergrösserte und schliesslich zu einer Halbinsel von rechteckiger Gestalt, 140 m Länge und 12 m Höhe wurde. Am 22. März folgte ein weiterer Lavaausbruch aus dem Gipfelkrater, dieser Strom floss am Nordrand der Sciara über die Lava vom Februar/März 1954 hinweg in zwei Armen ins Meer. Die Laven waren schwarzgraue Basalte mit 49. 80 und 49. 92 % SiO_2. Am 25. Mai stiessen im Gipfelkrater ausser zahlreichen Fumarolen zwei Hauptbocchen reichlich Gase aus und hatten periodisch Schlacken- und Aschenausbrüche. Ausserdem stiegen alle 15-46 Minuten Lavafontänen aus einer kleinen Bocca auf und selten war eine vierte, spaltenartige Bocca tätig. die Fontänen erhoben sich 60-150 m.

Am 3. Januar 1956 begann wieder ein stärkerer Ausbruch. ein Lavastrom floss langsam über die Sciara ins Meer; am 7. Februar verstärkte sich die Tätigkeit wieder. Später (Frühjahr?) waren zwei Hauptkrater tätig, deren einer am Boden 5 Einzelöffnungen hatte, aus denen Lavaglut leuchtete und in unregelmässigen Abständen augitreiche Schlacken 200 m hoch geworfen wurden. Der zweite Krater war seltener tätig, die Dauer der Ausbrüche schwankte zwischen 20 Sekunden und 2 Minuten. Im August 1956 folgten sich die Ausbrüche oft nach langen Pausen — bis zu 7 Stunden — und warfen unter Donnern rotglühende Schlacken mehrere 100 m hoch (4, 12, 66, 67).

Vesuv

Der Vesuv ist während der Berichtszeit weiter ruhig geblieben, obgleich z. B. im November 1954 die Temperaturen der Fumarolen bis 870°C anstiegen (67).

Santorin

Am 9. Juli 1956 fand auf Santorin ein schweres Beben statt, aber keine Eruption des Eliasberges, wie irrtümlich in der Tagespresse berichtet wurde. Die aufsteigenden « Rauchwolken » waren durch Erdrutsche ausgelöste Staubwolken (67).

QUELLENVERZEICHNIS

1) Briefliche Mittelung von Herrn D. R. Gregg, Rotorua.
2) Briefliche Mitteilung I. K. H. Prinzessin Sigismund von Preussen, La Barranca.

3) Briefliche Mitteilung von Herrn Prof. Dr. F. Termer, Hamburg.

4) D. Abbruzzese, C. Cavallaro: *L'eruzione sottomarina di Stromboli del 28 febbraio 1955.* « Stromboli » 4, Messina, 1956, p. 25-29.

5) F. Bachmann: *Flug über den Vatnajökull auf Island.* Leben und Umwelt, Aarau, 1956, p. 121-127.

6) G. A. Ball and D. G. James: *Dust in the stratosphere over western Britain on April 3 and 4, 1956.* Meteor. Mag. 85, 1956, p. 293-297.

7) A. F. Banfield, C. H. Behre and D. St. Clair: *Geology of Isabela (Albemarle Island), Archipilago de Colon (Galapagos).* Bull. Am. Geol. Soc. 67, 1956, p. 215-234.

8) L. Barrabé: *L'éruption de la Soufrière de la Guadeloupe.* Soc. géol. France, C. R. somm. séanc., 1956, p. 233-234.

9) L. Barrabé: *L'évolution de l'éruption de la Soufrière de la Guadeloupe.* Soc. géol. France, C. R. somm. séanc., 1956, p. 305-306.

10) F. M. Bullard: *Volcanic Activity in Costa Rica and Nicaragua in 1954.* Trans. Am. Geoph. Union 37, 1956, p. 75-82.

11) F. M. Bullard: *Active Volcanoes of Central America.* XX Congr. Geol. Intern. Mexico, 1956, Resumenes trabajos presentados, p. 6.

12) C. Cavallaro: *L'attività effusiva dello Stromboli del 22 marzo 1955.* « Stromboli » 5, Messina, 1956, p. 15-17.

13) G. Cumin: *Su l'attività eruttiva terminale dell'Etna, iniziatasi il 25 giugno 1955.* « Stromboli » 4, Messina, 1956, p. 3-9.

14) R. S. Dietz and M. J. Sheehy: *Transpacific Detection of Myojin Volcano Explosions by Underwater Sound.* Bull. Geol. Soc. Am., 65, 1954, p. 941-956.

15) J. J. Dozy: *Some notes on the Volcanoes of Guatemala.* Bull. volcanol., II/VIII, 1949, p. 47-67.

16) N. H. Fisher: *Catalogue of the active Volcanoes and Solfatara Fields of Melanesia.* Napoli, 1957.

17) R. L. Fisher, H. Kuno, R. Morimoto, N. Nasu: *Geological Results of the Transpacific Expedition.* Bull. Geol. Soc. Am., 65, 1954, p. 1252.

18) H. L. Foster: *Volcanic Activity in Japan.* Volcano Letter 526, 1954, p. 7.

19) H. L. Foster and A. C. Mason: *Activity in 1953-54 of Mihara-yama, Oo-shima, Japan.* Science 121, 1955, p. 876-877.

20) C. Fries and C. Gutierrez: *Activity of Paricutin Volcano during the Year 1952.* Tr. Am. Geoph. Union, 1954, p. 486-494.

21) A. Gädicke: *Die Erde bebt.* Kristall, Hamburg, 1956, p. 414-415.

22) G. S. Gorschkov: *Erster historischer Ausbruch des Vulkans Besymjannaja.* Bull. vulkanol. Stat., No. 24, Moskau, 1956, p. 70 (russisch).

23) D. R. Gregg: *Eruption of Ngauruhoe 1954-55.* New Zealand Jour. Sci. Techn., 37, 1956, p. 675-688.

24) D. R. Gregg: *Eruption of Ngauruhoe, January 1956.* New Zealand Jour. Sci. Techn., 38, 1957, p. 683-685.

25) N. J. Guest: *The Volcanic Activity of Oldonjo L'Engai 1954.* Rec. Geol. Survey Tanganyika. Dodoma, 1956, p. 56-59.

26) G. Hantke: *Das Vulkangebiet zwischen den Seen Ranco und Puyehue in Süd-Chile.* Bull. volcanol., II/VII, 1940, p. 75-83.

27) G. Hantke: *Übersicht über die vulkanische Tätigkeit 1951-1953.* Bull. volcanol., II/XVI, 1955, p. 71-113.

28) A. Heim: *Die Schweizer Virunga-Expedition in Zentral-Afrika 1954-1955.* Die Erde, Berlin, 1956, p. 51-62.

29) K. Klemmer: *Eine Ätna-Besteigung.* Natur und Volk 86, Frankfurt (Main), 1956, p. 50-52.

30) I. I. Kurenkov: *Volcanic Influence upon the Fluvial Fauna.* Priroda, 12/1957, Moskau, 1957, p. 49-54 (russisch).

31) G. A. Macdonald and A. Alcaraz: *Philippine Volcanoes during 1953 and early 1954.* Volcano Letter 523, 1954, p. 1-5.

32) G. A. Macdonald and J. P. Eaton: *The Eruption of Kilauea Volcano in May 1954.* Volcano Letter 524, 1954, p. 1-9.

33) G. A. Macdonald and J. P. Eaton: *The 1955 eruption of Kilauea Volcano.* Volcano Letter 529/530, 1955, p. 1-10.

34) A. R. McBirney: *Recent Volcanic Activity in Central America.* Volcano Letter 527, 1955, p. 1-2.

35) A. R. McBirney: *Thoughts on the Eruption of the Nicaraguan Volcano Las Pilas.* Bull. volcanol., II/XVII, 1955, p. 113-117.

36) A. A. Menjailow: *Der Vulkan Schewelutsch, sein geologischer Bau, seine Zusammensetzung und seine Ausbrüche.* Arbeit. vulkanol. Laborat. Akad. Wissensch. UdSSR, No. 9, Moskau, 1955, 264 pp. (russisch).

37) H. Meyer-Abich: *La erupcion del volcano Izalco (El Salvador) del 28 de febrero de 1955 y su activitad hasta principios de 1956.* Anal. Serv. Geol. Nac. El Salvador, Bol. 2, San Salvador, 1956, p. 3-18.

38) H. Meyer-Abich: *Los Volcanes activos de Guatemala y El Salvador (America Central).* Anal. Serv. Geol. Nac. El Salvador, Bol. 3, San Salvador, 1956, p. 1-102.

39) T. Minakami: *Report on Volcanic Activities and Volcanological Studies in Japan for the Period from 1951 to 1954.* Bull. volcanol., II/XVIII, 1956, p. 39-76.

40) T. Minakami: *Activity of Mount Asama.* Volcano Letter 523, 1954, p. 8.

41) R. Morimoto and J. Ossaka: *The 1952-53 Submarine Eruption of the Myojin Reef near the Bayonnaise Rocks, Japan.* Bull. Earthq. Res. Inst., 33, Tokyo, 1955, p. 221-250.

42) G. Mueller: *The Birth of a « Maar-Type » Volcano at Riniñahue,*

Southern Chile. XX Congr. Geol. Intern. Mexico, 1956. Resumenes trabajos presentados, p. 16.

43) E. H. Muller, W. Juhle, H. W. Coulter: *Current Volcanic Activity in Katmai National Monument.* Science 119, 1954, p. 319-321.

44) S. Murauchi: *Geophysical Studies of Volcano Suwanosejima in the Tokara-Islands.* Bull. Nat. Sci. Museum, Tokyo, 1954, p. 13-28.

45) M. Neumann van Padang: *Vulkanische Werking in Afrika.* Meded. Afr. Inst., 12, 1955, Sep.

46) B. I. Piip: *Der Zustand der tätigen Vulkane in nördlichen Kamtschatka 1954.* Bull. vulkanol. Stat., No. 24, Moskau, 1956, p. 14-20 (russisch).

47) B. I. Piip: *Kljutschewskaja Sopka, ihre Ausbrüche 1944-45 und in der Vergangenheit.* Arbeit. vulkanol. Laborat. Akad. Wissensch. UdSSR, No. 11, Moskau, 1956, 312 pp. (russisch).

48) A. F. Richards: *Volcanic Eruptions of 1953 and 1948 on Isabela Island, Galapagos Islands, Ecuador.* Volcano Letter 525, 1954, p. 1-3.

49) A. F. Richards: *Vulcanism in Eastern Pacific Basin 1954-55.* XX. Congr. Geol. Intern. Mexico, 1956. Resumenes trabajos presentados, p. 18.

50) A. F. Richards and R. S. Dietz: *Eruption of Bárcena Volcano, San Benedicto Isl., Mexico.* Proc. Eighth Pac. Sci. Congr. II, Manila, 1956, p. 157-176.

51) E. Rudolph: *Licancábur, Mountain of the Atacameños.* The Geograph. Review, April 1955, p. 151-171.

52) G. L. Snyder: *Eruption of Trident Volcano, Katmai National Monument,* February-June 1953. U. S. Geol. Survey, Circ. 318, 1954, 7 pp.

53) W. Sullivan: *About Antarctica.* Natural History, Jan. 1957, p. 9-15.

54) A. Suwa: *The Eruption of Sakura-Jima in 1955.* Jour. Geol. Soc. Japan, 62, 1956, p. 115-116.

55) G. A. Taylor: *Australian National Committee on Geodesy and Geophysics. Report of the Sub- committee of Volcanology 1953. Review of Volcanic Activity in the Territory of Papua-New Guinea, the Solomon and New Hebrides Islands, 1951-1953.* Bull. volcanol., II/XVIII, 1956, p. 25-37.

56) H. Tsuya: *On the Recent explosive Eruption of Volcano Sakura-Jima, Southern Kyushu, Japan I.* Bull. Earthq. Res. Inst. 34, Tokyo, 1956, p. 307-333.

57) H. Tsuya, A. Okada, T. Watanabe: *Evolution of Mihara Crater, Volcano Oshima, Izu, in the Course of its Activities since 1874.* Bull. Earthq. Res. Inst. 34, Tokyo, 1956, p. 33-59.

58) R. Weyl: *Geologische Wanderungen durch Costa Rica I : Die Vul-*

kane der Cordillera Central. Natur und Volk 86, Frankfurt (Main), 1956, p. 13-24.

59) H. Williams and H. Meyer-Abich: *Volcanism in the Southern Part of El Salvador.* Univ. of Calif. Publ. Geol. Sci. 32, 1955, p. 1-64.

60) W. I. Wlodawetz, G. S. Gorschkov, B. I. Piip: *Katalog der tätigen Vulkane der UdSSR.* Bull. vulkanol. Stat. No. 25, Moskau, 1957 (russisch).

61) I. Yokoyama: *Geomagnetic Studies of Volcano Mihara.* 8th Paper. Bull. Earthq. Res. Inst. 35, Tokyo, 1957, p. 567-572.

62) *Volcano Notes and News and Hawaiian Observatory Reports in:* Volcano Letter 523-530, Honolulu, 1954-1955.

63) *Hawaiian Volcano Observatory Summary* 1-4, 1956.

64) *Ein Vulkanausbruch.* Die Sowjetunion, Moskau, 1956, p. 9.

65) *Vulkan unter dem Eis.* Kristall, Hamburg, 1956, p. 683-685.

66) *Ausbruch des Stromboli.* Umschau, 1956, p. 650-651.

67) Nachrichten und Fotos in der Tagespresse, ferner nach:
Neues Jahrb. Geol. Paläont. Monatsh., Stuttgart, 1954-1956;
The Sphere, London, 1954-1956.

68) G. A. Taylor, J. G. Best and M. A. Reynolds: *Eruptive Activity and associated Phenomena, Langila Volcano, New Britain.* Bur. Min. Res. Geol. Geoph., Rep. 26, Canberra, 1957, 53 pp.

69) M. A. Reynolds and J. G. Best: *The Tuluman Volcano, St. Andrew Strait, Admiralty Islands.* Bur. Min. Res. Rep. 33, Canberra, 1957, 38 pp.

TAFELN

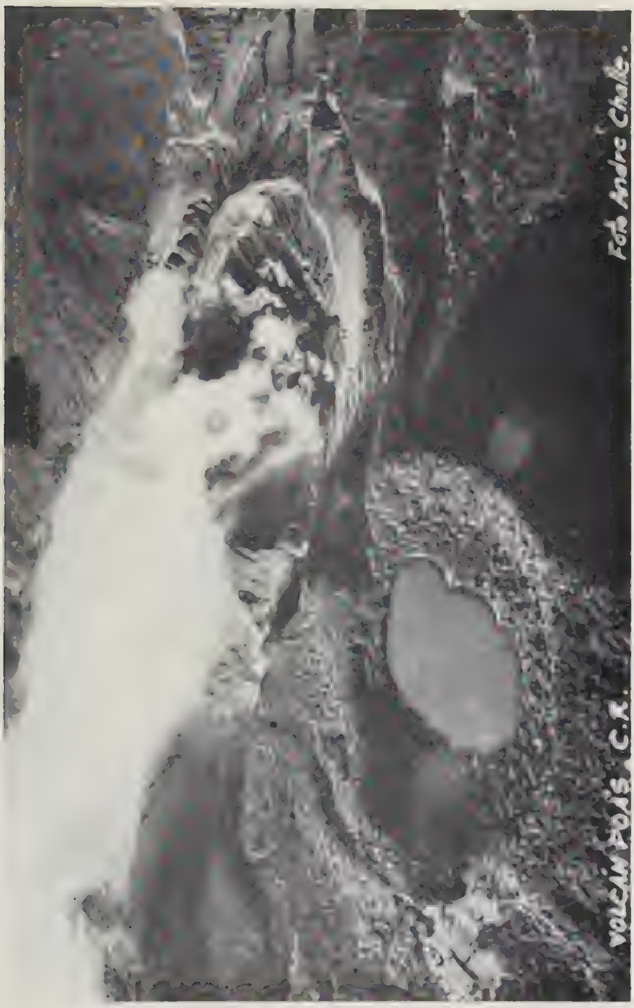


Abb. 1 Süd- und Mittelkrater des Poás im August 1951

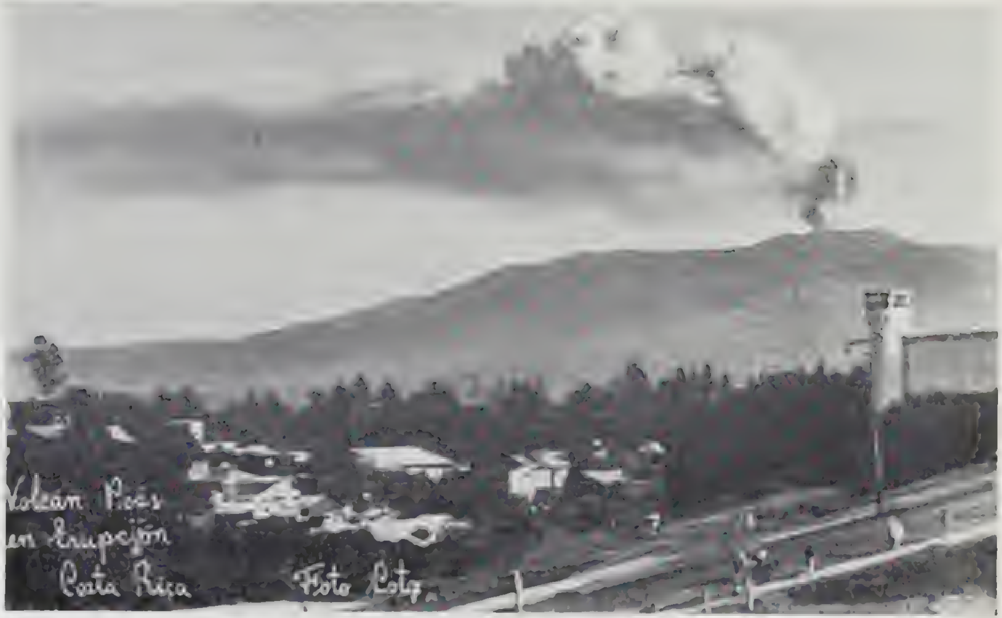


Abb. 2: Der Poás in Tätigkeit im November 1954.

HISASHI KUNO
Geological Institute University of Tokyo

Origin of Cenozoic Petrographic Provinces of Japan and Surrounding Areas

(With 12 figures)

Abstract

Three petrographic provinces can be recognized in the Cenozoic volcanic fields of Japan and surrounding areas. A province of a tholeiite series lies on the Pacific side of the Japanese Islands and includes the Izu Islands, whereas that of an alkali rock series occupies the Japan Sea side of the Islands with a narrow offshoot extending across central Honsyū (Honshū) and a continuation westward to Korea and Manchuria. A province of a calc-alkali rock series is superposed on the two provinces and occupies the greater part of the Japanese Islands exclusive of the Izu Islands and the islands in the Japan Sea southwest of Honsyū and north of Kyūsyū (Kyūshū). The boundary lines between the tholeiite and alkali provinces are located very closely to those between the areas where earthquakes occur at depths shallower than about 200 km and those for deeper ones. It is suggested that the parental tholeiite magma is produced by partial melting of the peridotite layer at depths shallower than 200 km. In the Izu Islands, except Nii-zima(Nii-jima) and Kōzu-sima(Kōzu-shima) close to Honsyū, the magma erupts to the surface without assimilating granitic material because the granitic layer is absent, resulting in volcanoes made up exclusively of the tholeiite series. The parental alkali olivine basalt magma is produced by partial melting of the peridotite layer at depths greater than 200 km. In the Japan Sea region, Korea, and Manchuria, it erupts to the surface without assimilating the

granitic material, although it passes through a thick granitic layer, resulting in volcanoes made up exclusively of the alkali series. However, in the Cenozoic orogenic belt of the Japanese Islands, both types of parental magma assimilate granitic material during passage to the surface and erupt to form volcanoes of the calc-alkali series.

Introduction

It has long been known that most Cenozoic volcanic rocks of the Japanese Islands belong to the basalt-andesite-dacite-rhyolite series. The occurrence of alkali volcanic rocks in some islands north of Tyūgoku (Chūgoku), southwestern Honsyū, and north of Kyūsyū was first pointed out by Kōzu (1911, 1912, 1913). Tomita (1935) emphasized the existence of a province of an alkali rock suite extending from the Japan Sea coast of southwestern Honsyū and north Kyūsyū to north Korea and Manchuria. He concluded that the parental magma of the province is the olivine basalt magma-type of Kennedy (1933) whereas that of the province of the Japanese Islands is the tholeiite magma-type which Tomita considered to have been derived from the former by assimilation of siliceous rocks.

Several « volcanic zones » are distinguished among the Quaternary volcanoes of Japan, and attempts have been made by many authors to find mineralogical or chemical differences between the individual « volcanic zones » (Koto, 1916; Tsuya, 1937; Taneda, 1951; Katsui, 1954). Katsui showed that the rocks of the « Tyōkai(Chōkai) Zone », which extends from southwest of Hokkaidō to the Japan Sea coast of northeastern Honsyū, have higher $Na_2O + K_2O$ contents than those of the other « volcanic zones », especially than those of the « Nasu Zone » lying to its east.

It is true that some of the volcanoes are arranged in definite zones (Fig. 1) and such arrangement is probably controlled by major or minor structural weaknesses. However, there is no reason to believe that the volcanoes belonging to a single zone should have a common parental magma or should have been formed through a common process and therefore should have common mineralogical or chemical

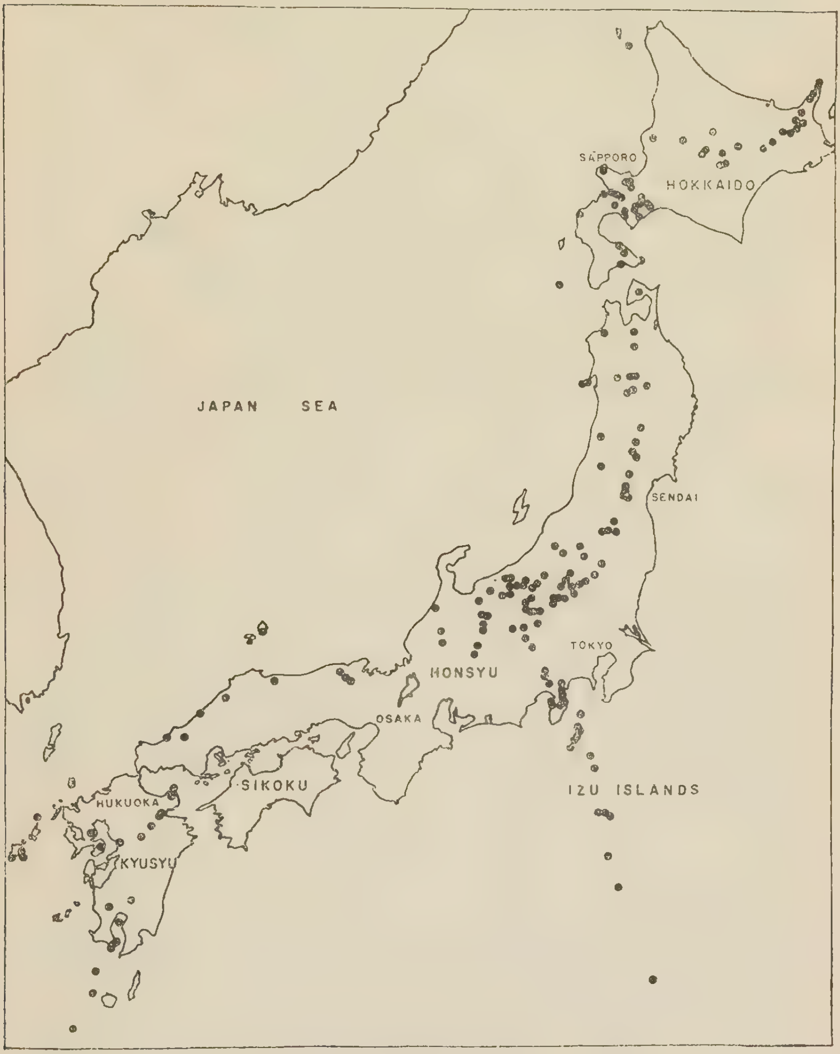


Fig. 1. - Distribution of the Quaternary volcanoes in the Japanese Islands.

characteristics. Thus according to KATSUI (1953) the rocks of Risiri(Rishiri) Volcano, northwest of Hokkaidō, have a high alkali content like those of the « Tyōkai Zone », yet it lies at the northern extremity of the « Nasu Zone » whose rocks are generally low in alkalies. Tsuya (1937) divided the « Huzi (Fuji) Zone », which extends from central Honsyū to the Izu-Mariana Arc, into two subzones according to chemical compositions of the lavas, — the northern subzone (« Huzi Zone » proper) being characterized by higher content of alkalies. According to Kuno (1952, 1953 c), the rocks of the northern subzone have mineralogical characteristics which may be due to contamination of magma by granitic or siliceous sedimentary material (hypersthenic rock series), whereas those of the southern subzone are free from contamination (pigeonitic rock series). He also demonstrated that the two subzones are completely gradational with regard to mineral composition.

The writer believes that in discussions of relations between rock genesis and tectonic environments, lateral variations in rock characteristics of separate volcanoes should be examined rather than comparisons of the « volcanic zones ». It is also necessary to classify the rocks from the view point of recent theories of petrogenesis. Confusion appears to exist among petrologists concerning the definition of the calc-alkali series and the tholeiite series. All andesites are generally considered as calc-alkali rocks, but it has been shown that some andesites are pure fractionation products of the tholeiite magma whereas others are derived through contamination (the calc-alkali rocks) (Kuno, 1950; Tilley, 1950).

Acknowledgment

For the present study, it was necessary to examine many thin sections of the Japanese volcanic rocks as well as those of other well-known volcanic provinces of the world. This was rendered possible through the courtesy of Professors Y. Kawano and K. Yagi of Tōhoku University, Mr. K. Sawamura of the Geological Survey, Professor T. Ishikawa and Mr. Y. Katsui of Hokkaidō University, Asst. Professor T. Samesima of the Sizuoka(Shizuoka) University, Dr. T. P. Thayer of the U. S. Geological Survey and Dr. R. L. Hay of the University of California. The writer's thanks are also due to Professor C. E. Tilley and Dr. S. O. Agrell of Cambridge University and to Dr. H. Neumann of the Mineralogical and Geological Museum of Oslo for gifts of Scottish Tertiary rocks, to Dr. K. v. Kelkar of Fergusson College, Poona, India, for a gift of Deccan basalt, and Dr. P. Scorza of Brazil for a gift of Parana basalt. The writer is greatly indebted to Professor C. Tsuboi of University of Tokyo for criticism on the geophysical problems, to Dr. A. Miyashiro of the Geological Institute, Drs. G. Corwin and H. L. Foster of the U. S. Geological Survey for helpful discussion on the result, and to Dr. T. Katsura and Mr. H. Haramura of the Tokyo Institute of Technology for chemical analyses of rocks. A part of the cost of the present study was defrayed by a much appreciated grant from the Government Fund for Scientific Research.

Igneous Rock Series

Holmes (1921) classified igneous rocks into alkali-series and calc-alkali-series on the basis of the SiO_2 value in a variation diagram of a rock suite « for the point where the lime-curve bisects the vertical distance between the soda-and potash-curves ». He also recognized the existence of intermediate series.

Later, Peacock (1931) proposed a four-fold classification of igneous rocks on the basis of the alkali-lime index which is represented by the SiO_2 value for the intersection of the CaO and $Na_2O + K_2O$ curves of a variation diagram. Peacock's method has become so familiar to petrologists that Holmes' original work has been generally overlooked.

As such a classification is entirely arbitrary, it is inadequate for studying the genesis of igneous rock suites and the origin of petrographic provinces.

The three-fold classification of igneous rocks as shown in Table 1 is based entirely on genesis. Peacock's index can distinguish alkali rock series (hereafter called the alkali series) from calc-alkali rock series (the calc-alkali series) but fails to distinguish the latter from tholeiite series. Thus, the index for the alkali series is generally below 53, whereas those for the calc-alkali and tholeiite series range from 55 to 67. However, each series has a characteristic assemblage of mafic silicate minerals and course of the mineral evolution.

Table 1. - Igneous rock series

Tholeiite series

Tholeiitic basalt → andesite → dacite → rhyolite
Gabbro → Fe-rich gabbro → granophyre

Calc-alkali rock series

Olivine basalt → andesite → dacite → rhyolite
Gabbro → diorite → granodiorite → granite

Alkali rock series

$$\text{Alkali olivine basalt} \rightarrow \left\{\begin{matrix}\text{mugearite}\\ \text{trachyandesite}\end{matrix}\right\} \rightarrow \left\{\begin{matrix}\text{trachyte}\\ \text{alkali}\\ \text{rhyolite}\end{matrix}\right.$$

Essexite ——→ monzonite ——→ syenite
Feldspathoid-bearing rocks ————→

Mineralogy of the rock series

Tholeiite series. — The evolution of the mafic minerals through various fractionation stages has been traced most completely in the tholeiite series. In the intrusive masses of this series such as Skaergaard (Wager and Deer, 1939), Karroo (Poldervaart, 1944; Walker and Poldervaart, 1949), Palisade (Walker, 1940), and Dillsburg (Hotz, 1953), the evolution is as follows :

Mg-olivine → bronzite-hypersthene → pigeonite Fe-olivine
diopside ——→ augite ————→ ferroaugite

The pigeonite has usually been inverted to hypersthene owing to slow cooling.

In some cases such as the Hawaiian quartz dolerite-granophyre series (Kuno and others, 1957), Fe-olivine does not form and ferropigeonite is the only mafic silicate mineral crystallizing in the latest stage. An outstanding feature of this series is the absence of OH-bearing minerals except in a few examples where they occur in the latest stage.

The volcanic phase of the tholeiitic mafic magma is represented by the basalts of Deccan, Columbia River, Farana Basin, a part of the Brito - Arctic region, the Hawaiian primitive shields, and the Izu-Hakone region. According to the writer's microscopical observations, these rocks have common mineralogy. The groundmass pyroxene ranges from augite to pigeonite, with or without subcalcic augite as an intermediate member, and silica minerals are present interstitially whereever the groundmass has high crystallinity. Olivine or hypersthene may occur in the groundmass, but they are invariably surrounded by reaction rims of pigeonite.

The volcanic phase of the tholeiite fractionation products is the pigeonitic rock series (abbreviated as P series in this paper) which was first recognized in rocks of the Izu-Hakone region (Kuno, 1950). It covers a composition range from olivine basalt to pyroxene dacite and is characterized by the occurrence of pigeonitic clinopyroxenes in the groundmass. As the fractionation proceeds, the groundmass pyroxene changes in composition from augite (in basalt) to pigeonite and ferropigeonite (in andesite and dacite). Hornblende and biotite do not form in this series.

Thus the mafic mineral evolution is as follows :

$$\begin{tikzcd}
\text{Mg-olivine} \arrow[r] & \text{hypersthene} \arrow[r] & \text{pigeonite} \arrow[r] & \text{ferropigeonite} \\
& \text{diopside} \arrow[r] & \text{augite} \arrow[ur] &
\end{tikzcd}$$

It was shown elsewhere that the mafic mineral evolution of the P series resembles closely that of the Hawaiian quartz dolerite — granophyre series (Kuno and others, 1957). The P series of the Izu-Hakone region is associated with plutonic and hypabyssal rocks containing inverted pigeonite characteristic of tholeiitic gabbro and dolerite.

The volcanic phase of the tholeiite series may show mafic mineral evolution slightly different from that of the P series in the later stage. Thus, in some andesite and dacite closely associated with the P series, such as the Asio(Ashio) dikes (see Table 5), a ferroaugite (or ferropigeonite) — Fe-olivine assemblage like that common in the intrusive phases is observed. As the mafic mineral evolution in the early to middle stages is essentially the same as that of the P series, these rocks may be grouped with this series. However, in some Tertiary tholeiitic basalt and associated andesite in Japan, pigeonite does not form and ferroaugite is the only mafic silicate mineral in the later stage of fractionation. Such rocks are not grouped with the P series.

Calc-alkali series. — The calc-alkali series is typically represented by the volcanic hypersthenic rock series (H series) which was recognized also in the Izu-Hakone rocks (Kuno, 1950). It ranges in composition from olivine basalt to biotite rhyolite and is characterized by the occurrence of orthopyroxene in the groundmass instead of pigeonite. As the fractionation proceeds, the groundmass pyroxene changes from augite plus hyperstene (basalt and andesite) to hypersthene or ferrohypersthene (dacite). The mafic mineral evolution is as follows :

Phenocrysts : ——

$$\begin{tikzcd}
\text{Mg-olivine} \arrow[r] & \text{hypersthene} \arrow[r] & \text{hornblende} \arrow[r] & \text{biotite} \\
 & \text{augite} \arrow[ur] & &
\end{tikzcd}$$

Groundmass : ——

$$\begin{tikzcd}
\text{hypersthene} \arrow[rr] & & \text{ferrohypersthene} \\
\text{augite} \arrow[ur] & &
\end{tikzcd}$$

Thus Bowen's discontinuous reaction series applies in its original form to the phenocrysts of this series. The mineralogy of the H series indicates lower temperatures of crystallization than those of the P series. In the basalt of this series olivine may occur in the groundmass where it is invariably surrounded by reaction rims of hypersthene, and silica minerals may or may not be present. The olivine phenocrysts often include small picotite octahedra. Xenocrysts of quartz and sodic plagioclase with dust inclusions (Kuno, 1950) are common. Basalt having such characteristic mineralogy is often found in the

High Cascade volcanoes where it is described under the name « olivine basalt » and « basaltic andesite ». The basalt of Paricutin Volcano also belongs to this type.

The rocks of the H series form the greater part of the Quaternary volcanoes of Japan and also appear to occur commonly in those of the High Cascades and Andes, so far as observed by the writer.

Some calc-alkali volcanic rocks contain augite alone in the groundmass without accompanying orthopyroxene, probably because the pyroxenic components crystallizing in the groundmass stage had a composition on the augite side of the immiscibility field of the pyroxene solid solution. Such rocks are found in Pleistocene or Recent lavas of Burma and late Mesozoic lavas of Manchuria.

The plutonic phase of this series is represented by the gabbro — diorite — granodiorite association such as the middle Miocene intrusive rocks around the Huzi Volcano. In this area, there is almost complete gradation from the volcanic phase, through the hypabyssal, to the plutonic, all having common mineralogical characteristics.

In gabbro of this series, hypersthene has exsolution lamellae of augite parallel to 100 less abundantly than the tholeiitic gabbro hypersthene, indicating low Ca content in the primary phase. Inverted pigeonite is entirely lacking, whereas interprecipitate hornblende is common.

The question whether all granite and granodiorite are products of fractionation of the calc-alkali basalt magma is not discussed here.

Alkali series. — The best examples of the alkali series are afforded by the volcanic associations of oceanic islands such as Hawaii (MACDONALD, 1949) and Mauritius (WALKER and NICOLAYSEN, 1954). Similar associations are also common in non-orogenic continental regions such as East Manchuria (KUNO, 1953 b) and Scotland (BAILEY and others, 1924).

The olivine basalt of this series is mineralogically distinct from basalts of the other series. It contains Mg-olivine and augite (sometimes titaniferous) in the groundmass and also interstitial alkali feldspar instead of silica minerals. Hypersthene and pigeonite are entirely absent. There is no indication of the reaction relation between the olivine and augite, and the two minerals continue crystallizing side by side until a late stage of fractionation (oligoclase andesite or mugearite stage) (Kuno and others, 1957). In some cases this association maintains even to the latest stage (trachyte stage) (Barth, 1942), but usually it is replaced by aegirine, alkali amphibole, or biotite in trachyte and alkali rhyolite.

Feldspathoid-bearing rocks have the same mafic mineral assemblage as the feldspathoid-free ones.

Plutonic and hypabyssal phases of this series are represented by differentiated intrusive sheets and laccoliths of alkali olivine dolerite, teschenite, and essexite. Comparatively simple association of rock types is found in doleritic trachyandesite sheets with schlieren of dolerite pegmatite and trachyte in the Sidara (Shidara) Basin, central Japan (Fig. 9) and olivine-rich dolerite — analcite syenite sheets of Atumi on the Japan Sea coast of northeastern Honsyū (Fig. 9). They show the same trend of mafic mineral evolution as in the volcanic phase.

Chemistry of the rock series

The tholeiite series differs from the alkali series in the relation between total alkali and SiO_2 contents as has been demonstrated in the Hawaiian rocks (Kuno and others, 1957).

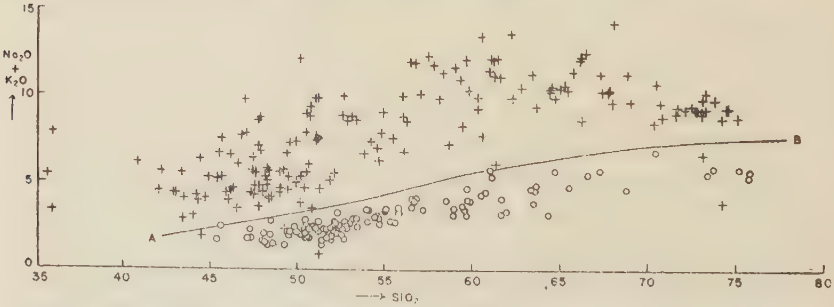


Fig. 2. - Total alkali — SiO_2 relation in the tholeiite and alkali series. Circles: — the P series (tholeiite series) of the Izu-Hakone region; crosses: — the alkali series of the Circum-Japan Sea region.

Table 2. - Average compositions of rocks of the Circum-Japan Sea alkali province (TOMITA, 1935).

Rock type	Limburgite -basanitoid	Basalt -trachybasalt	Trachy-andesitic basalt	Trachy-andesite	Trachyte	Trachy-rhyolite	Comendite
Range of SiO_2	< 45	45-50	50-55	55-60	60-65	65-70	70 <
No. of analyses	12	27	14	11	16	16	21
SiO_2	41.97	47.77	52.35	57.51	62.63	66.97	72.71
Al_2O_3	14.94	16.41	17.67	18.79	17.25	14.93	12.14
Fe_2O_3	4.73	3.29	3.17	2.63	2.13	1.55	2.12
FeO	7.56	7.20	5.75	3.18	2.34	2.44	2.25
MgO	8.43	5.94	3.16	1.38	0.40	0.27	0.16
CaO	11.34	9.34	7.61	4.00	2.21	1.28	0.62
Na_2O	3.02	3.44	4.24	5.02	5.34	5.30	4.26
K_2O	1.50	2.08	2.54	4.65	5.19	5.47	4.49
H_2O	2.83	1.45	1.14	1.18	1.55	1.12	0.84
TiO_2	2.10	2.19	1.71	1.11	0.55	0.43	0.28
P_2O_5	1.10	0.69	0.48	0.40	0.20	0.09	0.04
MnO	0.48	0.20	0.18	0.15	0.21	0.15	0.09
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
SI	34	27	17	8	3	2	1

This is also illustrated in Fig. 2, in which the rocks of the Izu-Hakone P series and the Circum-Japan Sea alkali rocks are plotted. The two series occupy distinct areas separated by line AB. A few alkali rocks whose points lie within the field of the P series may be tholeiitic or calc-alkali rocks occurring within the alkali province, or the analyses may be inferior.

Only the average compositions of the Circum-Japan Sea

Table 3. - Average compositions of aphyric rocks of the Izu-Hakone pigeonitic rock series (KUNO, 1953 c).

Rock type	Basalt	Basalt -andesite	Andesite	Andesite -dacite
Range of SI	40-30	29-20	19-10	9-0
No. of analyses	5	26	15	4
SiO_2	49.7	53.8	60.3	72.0
Al_2O_3	15.3	14.8	14.9	12.8
Fe_2O_3	2.8	3.7	2.5	2.0
FeO	9.4	9.3	7.1	2.5
MgO	7.7	4.5	2.5	0.6
CaO	12.0	9.0	6.7	3.5
Na_2O	1.3	2.2	3.3	3.7
K_2O	0.3	0.5	0.8	1.3
H_2O +	0.3	0.4	0.4	0.5
H_2O –	0.3	0.4	0.2	0.2
TiO_2	0.6	1.2	1.1	0.6
P_2O_5	0.1	0.1	0.1	0.2
MnO	0.3	0.2	0.2	0.2
Total	100.1	100.1	100.1	100.1

alkali rocks and of the aphyric rocks of the Izu-Hakone P series are quoted in Tables 2 and 3 respectively.

The figures in Table 3 were calculated by grouping the rock analyses falling within equal intervals of the value $MgO \times 100/MgO + FeO + Fe_2O_3 + Na_2O + K_2O$ calculated therefrom, instead of grouping them on the basis of equal intervals of SiO_2 value. The reason for this procedure is as follows: It is known that the SiO_2 value does not change steadily throughout fractionation so that, if the average compositions are calculated on the basis of equal intervals of SiO_2, average values for lower SiO_2 represent wider ranges of fractionation stages than those for higher SiO_2. On the other hand, when the rock analyses are plotted in the ternary diagram MgO : FeO + Fe_2O_3 : Na_2O + K_2O, the fractionation trend of any rock suite is from the MgO-rich side of the diagram to the MgO-poor side; in other words, the value MgO × 100/MgO + FeO + Fe_2O_3 + Na_2O + K_2O invariably decreases as the fractionation proceeds. It has also been shown elsewhere (Kuno and others, 1957) that, through the fractionation of the Skaergaard tholeiite series and the Hawaiian alkali series, this value changes steadily with the amount of residual liquids formed at successive stages. The value has been called the solidification index (SI). It is assumed that the same relation holds for other rock series. If the rock analyses are grouped on the basis of the SI value, each group would represent approximately an equal interval of fractionation stages.

The P series and H series of Izu-Hakone differ from each other in the fractionation trend, as shown by plotting their compositions in the diagram MgO : FeO + Fe_2O_3 : Na_2O + K_2O (Kuno, 1953 a).

For the reason that the SI value represents a measure for the amount of residual liquids, it is more reasonable to construct a variation diagram for a rock suite by using the SI value as abscissa rather than SiO_2. In such a variation diagram, the SI value for the point where the CaO curve intersects the total alkali curve would serve to compare the fractionation stages of rock suites at which CaO becomes equal to Na_2O + K_2O. The SI value for this point is called hereafter the alkali-lime index although it differs from Peacock's alkali-lime index.

In Tables 4-11, the proposed alkali-lime indices are listed for many rock suites together with the corresponding CaO values.

Table 4 gives data for the differentiated intrusive masses of the tholeiite series. The index is lower than 11 and the CaO value is lower than 5.5 except in the three examples from Scotland given at the end of the table which have slightly higher indices and CaO values.

Table 4. - Differentiated intrusive masses of tholeiite series. In this and succeeding tables, the locality numbers refer to those given in Fig. 5.

Locality and author	Rock association	Alkali-lime index	$CaO = Na_2O + K_2O$
Skaergaard liquids (WAGER and DEER, 1939)	gabbro-granophyre	3	5.5
Dillsburg, Penna (HOTZ, 1953)	dolerite -granophyre	7	5.3
Palisade diabase, New Jersey (LEWIS, 1908; WALKER, 1940)	dolerite -granophyre	6	5.5
Elephant's Head dike and New Amalfi sheet (POLDERVAART, 1944)	dolerite -granophyre	5	4.9
Karroo dolerites in general (WALKER and POLDERVAART, 1949)	dolerite -granophyre	8	5.2
Semi (10) (KUNO, unpublished)	quartz dolerite -granophyre	8	5.0
Tasmania (EDWARDS, 1942)	dolerite -dolerite pegmatite	5*	5.0*
Palolo, Honolulu, Hawaii (KUNO and others, 1957)	quartz dolerite -granophyre	11	4.7
Scottish Carboniferous-Permian igneous rocks (TOMKEIEFF, 1937)	quartz dolerite series	17	5.3
Scottish late Paleozoic rocks (WALKER, 1935)	quartz dolerite, tholeiite and salic veins	17	6.1
Glen More Ring Dike (BAILEY and others, 1924)	quartz gabbro -quartz diorite	14	6.5

* By extrapolation.

Table 5 gives data for the volcanic phase of the same series (mostly P series). As judged from the description by Bandy (1937), the rocks of Easter Island belong to the P series. Similarity of the composition of the Easter dacite to that of the Hawaiian granophyre has been pointed out elsewhere (Kuno and others, 1957). The ranges of the index and CaO values in Table 5 are nearly identical to those for the intrusive phase, although the maximum index and CaO values for the volcanic phase attain to 13 and 5.8 respectively. The data given in Tables 4 and 5 except the three rock suites of Scotland are plotted in Fig. 3. The points lie within the field marked as the tholeiite series.

Table 5. - Volcanic tholeiite series (mostly pigeonitic rock series).

Locality and author	Rock association	Alkali-lime index	CaO = Na_2O+K_2O
Dikes near Asio (12) (Kuno, unpublished)	pigeonite andesite -pigeonite dacite	2*	4.1*
Izu-Hakone aphyric rocks (17) (Kuno, 1953 c)	basalt—andesite -dacite	9	4.5
Sidara Tertiary volcanic rocks (20) (Nagashima, 1953)	basalt—andesite	10	5.6
Nyohō-Akanagi volcano (11) (Yamasaki, 1954)	andesite—dacite	13	5.1
Easter Island (Bandy, 1937)	basalt—andesite -dacite—rhyolite	11	5.8
Mull tholeiite series (Bailey and others, 1924)	basalt—andesite -rhyolite	13	5.3
Iceland (Hoppe, 1938)	basalt—rhyolite	13	4.9

* By extrapolation.

It may also be noted in Tables 4 and 5 that the tholeiite series with ferroaugite (or ferropigeonite) — Fe-olivine assemblage in the later stage have indices lower than 8 (Skaergaard, Dillsburg, Elephant's Head dike and New Amalfi sheet, Semi, and dikes near Asio) whereas those with ferropigeonite only in the later stage have indices higher than 9 (Palolo, Izu-Hakone, Sidara, Nyohō-Akanagi, Easter Island, and Mull).

Data for the H series of Japan, High Cascades, and Paricutin are listed in Table 6. That the rocks belong to the series has been checked microscopically by the writer or ascertained from reliable descriptions. Except those of Izu-Hakone rocks, the indices for the H series are higher than 14 whereas the CaO values lie nearly within the same range as those of the tholeiite series. When plotted in Fig. 3, the points fall within the field marked as the calc-alkali series which is distinct from the field of the tholeiite series.

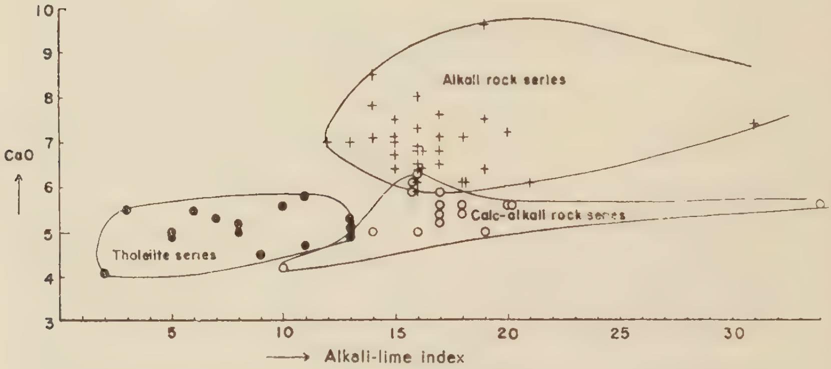


Fig. 3. - The CaO value plotted against the corresponding alkali-lime index proposed in this paper. Solid circles: — the tholeiite series; open circles: — the H series (calc-alkali series); crosses: — the alkali series.

The three rock suites of Scotland have an index — CaO relation corresponding to that of the calc-alkali series. They appear to belong to this series.

Examples of differentiated alkali intrusive masses in which

Table 6. - Volcanic calc-alkali rock series (hypersthenic rock series).

Locality and author	Rock association	Alkali-lime index	CaO = $Na_2O + K_2O$
Risiri Volcano (2) (Katsui, 1953)	basalt—andesite	17	5.4
(Osima-Ōsima Volcano (6) (Katsui, 1953)	basalt—andesite	16	5.9
Tyōkai Zone (9) (Katsui, 1954)	basalt—andesite	16	6.1
Asama Volcano (14) (Tsuya, 1934)	andesite—dacite	17	5.2
Izu-Hakone aphyric rocks (17) (Kuno, 1953 c)	basalt—andesite —dacite—rhyolite	10	4.2
Amagi Volcano (19) (Tsuya, 1937)	basalt—andesite —dacite	19	5.0
Sidara Tertiary volcanic rocks (20) (Nagashima, 1953)	andesite—dacite —rhyolite	14	5.0
Syōdo-sima Tertiary volcanic rocks (21) (Yamaguti, M., 1951)	andesite	34	5.6
Hutago Volcano (22) (Kawano, 1937)	andesite—dacite	18	5.6
Unzen Volcano (23) (Homma, 1936)	andesite—dacite	18	5.4
Aso Volcano (24) Pre-caldera rocks (Yamaguti, K., 1938) Post-caldera lavas (Komma and Mukai, 1938)	basalt—andesite —dacite andesite—rhyolite	17 16	5.9 6.3
Aira Caldera, pumice flows (25) (Yamaguti, K., 1937; 1938)	andesite—dacite —rhyolite	16	5.0
North-central Cascade Mountains, Oregon (Thayer, 1937)	basalt—andesite —dacite	17	5.6
Crater Lake, Oregon (Williams, 1942)	basalt—andesite —dacite	20	5.6
Paricutin Volcano, Mexico (Wilcox, 1954)	basalt—andesite	20*	5.6*

* By extrapolation.

Table 7. - Differentiated intrusive masses of alkali rock series.

Locality and author	Rock association	Alkali-lime index	CaO = $Na_2O + K_2O$
Sidara Tertiary intrusive sheet (20) (Kuno, unpublished)	trachyandesite -trachyte	16	5.9
Morotu, Sakhalin (1) (Yagi, 1953)	dolerite-analcite syenite	21	6.1

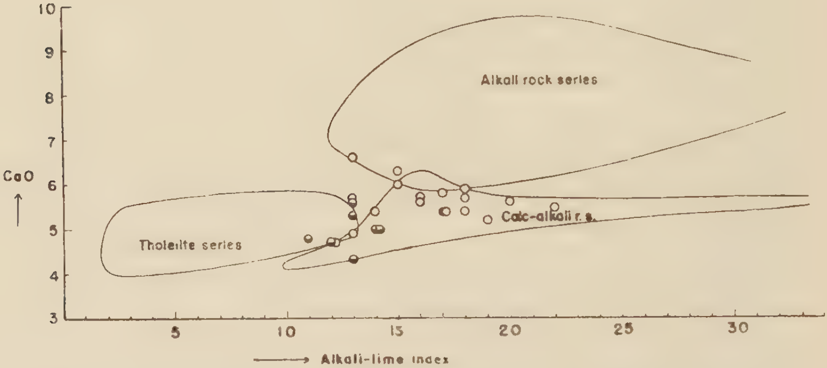


Fig. 4. - The CaO value plotted against the corresponding alkali-lime index proposed in this paper. Half-solid circles: — mixture of the P and H series; open circles: — rocks of the Circum-Pacific volcanic regions other than Japan (mostly calc-alkali series).

the fractionation trend has been traced by chemical analyses are scanty. Table 7 gives only two examples.

Tables 8 and 9 list data for the volcanic alkali series (partly intrusive) of the oceanic regions and non-orogenic continental regions respectively. No systematic difference can be recognized between the values for the rocks of these major units of the crust. The index for the alkali series (Tables 7, 8, and 9) ranges nearly within the same limits as those for the calc-alkali series, whereas the CaO value for the alkali

Table 8. - Volcanic alkali rock series of oceanic islands.

	Locality and author	Rock association	Alkali-lime index	$CaO = Na_2O + K_2O$
Pacific Ocean	Hawaiian Islands (Cross, 1915; Washington, 1923; Washington and Keyes, 1926; Macdonald, 1940, 1942, 1947; Macdonald and Powers, 1946; Wentworth and Winchell, 1947)	basalt—trachyte	16	6.8
	Marquesas Islands (Chubb, 1930)	basalt—trachyte, phonolite	15	7.1
	Samoan Islands (Macdonald, 1944)	basalt—trachyte	19	6.4
	Tahiti Island (Williams, 1933)	basalt—phonolite essexite—nepheline syenite	16	8.0
	Moorea Island (Williams, 1933)	basalt—trachyte phonolite	16	6.5
	Austral Islands (Smith and Chubb, 1927)	theralite—trachybasalt—phonolite	12	7.0
	Peter I Island, Antarctica (Broch, 1927)	basalt—trachyandesite	16	6.4
Indian Ocean	Mauritius Islands (Walker and Nicolaysen, 1954)	basalt—trachyte	15	6.7
	Kerguelen Islands (Edwards, 1938)	basalt—trachyte basanite—tephrite—phonolite	15 14	6.4 8.5
	Possession Island (Crozet I.) (Tyrrell, 1937)	trachybasalt—trachyandesite	15	7.5
	Heard Island (Tyrrell, 1937)	trachybasalt—trachyte, phonolite	16	7.3
Atlantic Ocean	Jan Mayen (Tyrrell, 1926)	trachybasalt—trachyandesite—trachyte	17	6.8
	Ascension Island (Daly, 1925)	basalt—trachyte—rhyolite	16	6.9
	Saint Helena (Daly, 1926-27)	basalt—trachyte, phonolite	16	6.8
	Gough Island (Barth, 1942)	basalt—trachyte	17	7.6

Table 9. - Volcanic alkali rock series of non-orogenic continental regions.

Locality and author	Rock association	Alkali-lime index	CaO = Na_2O+K_2O
Circum-Japan Sea province (Tomita, 1935)	trachybasalt-trachy-andesite-trachyte-rhyolite	15	7.0
Saisyū Island, South Korea (27) (Haraguti, 1930)	basalt-trachyandesite-trachyte	18	7.2
East Manchuria plateau basalt (28) (Kuno, unpublished)	basalt-mugearite	16	6.4
North-central Manchuria volcanoes (29) (Ogura and others, 1936, 1938, 1939)	leucite basanite	31	7.4
East Otago (Turner and Verhoogen, 1951)			
Strongly deformed subprov.	basalt-trachyte, phonolite	13	7.0
Moderately deformed subprov.	basalt-mugearite-nephelinite	14	7.8
Gisborne District, Australia (Edwards, 1940)	basalt-trachy-andesite	18	6.1
Central Victoria, Australia (Edwards, 1938)	basalt-olig. bas. -trachyte, phonolite	17	6.5
Ross Island, Antarctica (Stewart, 1956)	basalt-tephrite -trachyte - phonolite	17	7.1
Scottish Carboniferous-Permian igneous rocks (Tomkeieff, 1937)	teschenite series essexite series olivine basalt series	20 19 18	7.2 7.5 6.1
Mull alkali magma series (Bailey and others, 1924)	basalt-mugearite -trachyte	16	6.1
Mozambique, East Africa, alkali rock series (Holmes, 1916)	basalt-tephrite -trachyte	14	7.2
Laacher See District (Brauns, 1928)	leucite basalt, nepheline basanite, tephrite	19	9.6
Hopi-Navajo District (Williams, 1936)	basalt, monchiquite, minette, leucitite	36	8.1

Table 10. - Volcanic rocks including both calc-alkali rock series (hypersthenic rock series) and tholeiite series (pigeonitic rock series).

Locality and author	Rock association	Alkali-lime index	CaO = Na_2O+K_2O
Masyū Volcano (3) (KATSUI, 1955)	andesite—dacite	13	4.3
Yōtei Volcano (4) (KATSUI, 1956)	andesite—dacite	14	5.0
Usu Volcano (5) (YAGI, 1949)	andesite—dacite	11	4.8
Towada Caldera (7) (KAWANO, 1939; KUNO, unpubl.)	andesite—dacite	12	4.7
Akagi Volcano (13) (ŌTA, 1952; KATSURA, unpubl.)	andesite—dacite	14	5.0
Huzi Volcano (16) (TSUYA, 1937)	basalt—dacite	13	5.6
Sakura-zima Volcano (26) (YAMAGUTI, K., 1927)	andesite	13	5.3

series is generally higher. When plotted in Fig. 3, the points fall within a distinct field, although it overlaps slightly the field of the calc-alkali series.

Table 10 lists data for rocks of the Japanese volcanoes where the P and H series occur side by side and both were incorporated in obtaining the index and CaO value. They are plotted in Fig. 4, in which the outlines of the three fields are reproduced. As would be expected, the points lie either in the tholeiite field or in the calc-alkali field or close to them.

The data for the Circum-Pacific volcanic regions other than Japan are given in Table 11 and are plotted also in Fig. 4. Most of them fall within the calc-alkali field. The points for the rocks of Deception Island, Antarctandes, and the

Table 11. - Volcanic rocks of Circum - Pacific Zone, mostly calc-alkali rock series but partly tholeiite series.

Locality and author	Rock association	Alkali-lime index	CaO = Na_2O+K_2O
Kamchatka volcanoes (TOMKEIEFF, 1949)	basalt—andesite—rhyolite	18	5.4
Adak and Kanaga Islands, Aleusian (COATS, 1952)	basalt—andesite—dacite	17	5.4
Katmai, Alaska (FENNER, 1926)	basalt—andesite—rhyolite	17	5.4
Mount St. Helens, Washington (VERHOOGEN, 1937)	basalt—andesite—dacite	19	5.2
Newberry Volcano, Oregon (WILLIAMS, 1935)	basalt—andesite—rhyolite	17	5.8
Medicine Lake Highland, California (POWERS, 1932; ANDERSON, 1941)	basalt—andesite—rhyolite	18	5.9
Lassen Volcano, California (WILLIAMS, 1932)	basalt—andesite—rhyolite	22	5.5
Central Mexico including Paricutin (WILLIAMS, 1950)	basalt—andesite—rhyolite	20	5.6
Nicaragua (BURRI and SONDER, 1936)	basalt—andesite—rhyolite	13	5.7
Andes of Northern Patagonia (LARSSON, 1941)	basalt—andesite—dacite	15	6.0
Deception Island, Antarctica (BARTH and HOLMSEN, 1939; STEWART, 1956)	basalt—andesite trachyandesite	15	6.3
Jerry Island, Antarctica (STEWART, 1956)	andesite-dacite	18	5.7

(To be continued)

Locality and author	Rock association	Alkali-lime index	CaO = Na_2O+K_2O
Northeastern part of North Island, New Zealand			
Hantly-Kawhia subdivision (Henderson and Grange, 1926)	basalt—andesite nepheline basalt	13	6.6
Waihi, Coromandel (Morgan, 1924)	andesite—rhyolite	12	4.7
Aroha subdivision (Henderson and Bartrum, 1913)	andesite—dacite—rhyolite	13	4.9
Rotorua-Taupo region (Grange, 1937)	basalt—rhyolite	14	5.4
Quaternary volcanic rocks, Sumatra (Westerveld, 1952)	basalt—andesite—dacite—rhyolite	16	5.6
Krakatau group (Westerveld, 1952)	basalt—andesite—dacite—rhyolite	16	5.7

Hantly-Kawhia subdivision, New Zealand, fall within the alkali field. The Deception rocks are unusually high in Na_2O, yet their mineralogy corresponds generally to that of the calc-alkali series (Barth and Holmsen, 1939). The Hantly-Kawhia rocks are associated with nepheline basalt (Henderson and Grange, 1926) and appear to be allied to the alkali series.

Origin of the rock series

As seen from Tables 4, 5, 7, 8, and 9, the tholeiite and alkali series occur in the oceanic and non-orogenic continental regions and also in the orogenic belts. The calc-alkali series is characteristic of the orogenic belt and is entirely lacking in the oceanic regions. These facts strongly indicate that the tholeiite and alkali series are simply fractionation products of parental tholeiite and alkali olivine basalt magmas respectively, whereas the calc-alkali series is formed by fractionation of basaltic magmas contaminated by sialic materials.

From study of the Hawaiian basalts, Kuno and others (1957) concluded that neither the tholeiite magma nor alkali olivine basalt magma is the derivative of the other but that the two types of magma are generated independently by partial melting of the peridotite layer under different sets of temperature and pressure. It is also suggested that the tholeiite magma is formed at shallower portions of the layer, that is, under lower pressure, where the incongruent melting of enstatite, one of the constituents of the peridotite, would give rise to oversaturated liquid, whereas the alkali olivine basalt magma is formed in deeper portions where the olivine and enstatite of the peridotite would melt simultaneously to produce undersaturated liquid.

The evidence for contamination in the H series is the common existence of quartz and sodic plagioclase xenocrysts in the mafic members (Kuno, 1954). The plagioclase contains dust-like inclusions of glass which was formed by incipient melting of the mineral. In the salic members, the quartz xenocrysts appear to have been completely resorbed, whereas the plagioclase xenocrysts with dust inclusions remain in the core of some phenocrysts (Kuno, 1950).

The H series closely associated with the P series is most probably derived from the parental tholeiite magma contaminated by granitic or sedimentary rocks.

On the other hand, in certain volcanoes (see Table 13) as well as in Tertiary volcanic fields of Japan, such as the Noto peninsula and Setouti region, the H series is closely associated with alkali olivine basalt whereas tholeiitic basalt is entirely absent. Thus the derivation of the H series from the alkali olivine basalt magma is strongly indicated. Some alkali olivine basalt containing partly resorbed xenocrysts from granitic rock has orthopyroxene in pegmatitic patches or in cavities, representing transition in mineralogy to the H series.

Olivine phenocrysts in alkali olivine basalt commonly contain inclusions of small octahedral picotite, but this feature has rarely been observed in the Japanese tholeiites. Picotite inclusions are common in olivine phenocrysts in the H series also.

From these facts it is almost certain that some rocks of the H series are derived from the alkali olivine basalt magma and the remainder from the tholeiite magma.

Distribution of the rock series in the Quaternary volcanoes of Japan

Because the classification of the rock series based on the mineralogical characters is consistent with the chemical classification as shown in the foregoing section, we can distinguish the rock series simply by microscopical study of the rocks.

The association of the rock series in individual volcanoes

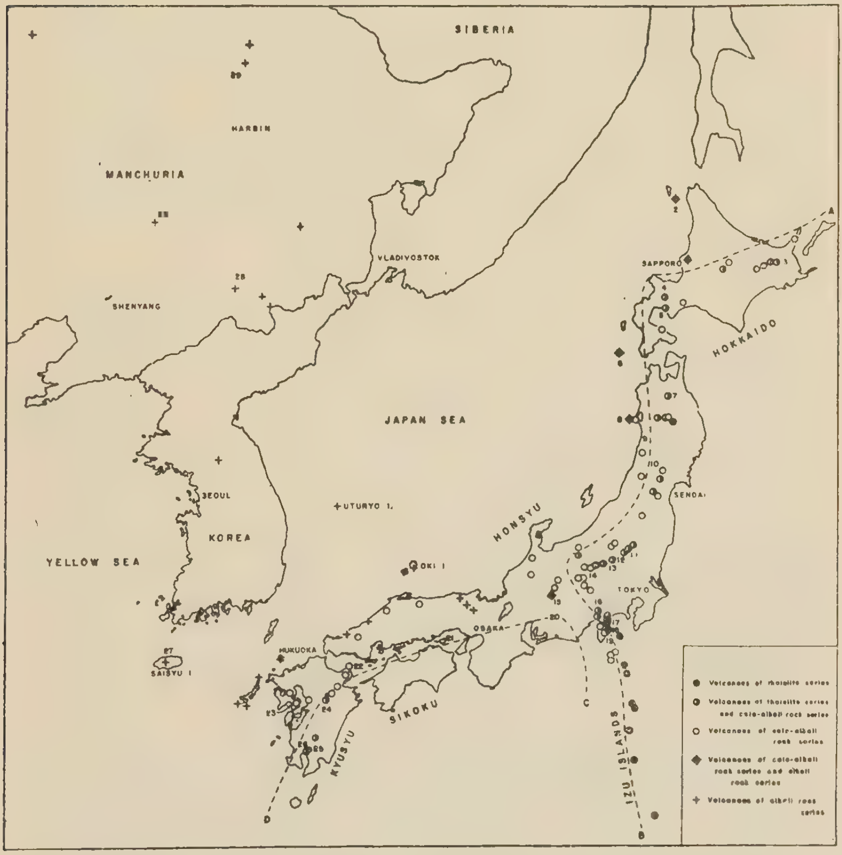

SIBERIA
HARBIN
MANCHURIA
SHENYANG
VLADIVOSTOK
JAPAN SEA
SAPPORO
HOKKAIDO
SENDAI
HONSYU
TOKYO
OSAKA
OKI I.
UTURYO I.
SEOUL
KOREA
YELLOW SEA
FUKUOKA
SAISYU I.
SIKOKU
KYUSYU
IZU ISLANDS
A
B
C
D
● Volcanoes of tholeiite series
◐ Volcanoes of tholeiite series and calc-alkali rock series
○ Volcanoes of calc-alkali rock series
◆ Volcanoes of calc-alkali rock series and alkali rock series
+ Volcanoes of alkali rock series

Fig. 5. - Distribution of the rock series in the Quaternary volcanoes of Japan, Korea, and Manchuria. Lines AB and CD represent boundary between the areas where the tholeiite series occurs and that where the alkali series occurs.

of Japan and surrounding areas were determined by examining many thin sections and also from reliable descriptions. The result is shown in Fig. 5.

As seen in the figure, the volcanoes of the Izu Islands, except the three rhyolite volcanoes just south of Izu Peninsula, consist exclusively of the tholeiite or P series, and two volcanoes (Taga and Yugawara) on the eastern coast of the Izu Peninsula near the northern end of the Izu Islands are made up largely of the same series. The tholeiitic aphyric rocks of this area have the compositions represented by the averages given in Table 3; they have low alkali content and a high $FeO + Fe_2O_3 : MgO$ ratio. Iwate Volcano in northeastern Japan also consists largely of the same series. The tholeiite province of the Izu Islands appears to extend southward as far as the volcanoes of the inner Mariana Arc. Iwō-zima (Iwō-jima), south of the Izu Islands is however made up of trachyandesite.

The volcanoes near the Japan Sea coast of southwestern Honsyū and northern Kyūsyū and those of Korea and Manchuria are made up exclusively of the alkali series. The rock types occurring in this region are alkali olivine basalt, trachybasalt, trachyandesite, mugearite, trachyte, and alkali rhyolite, with subordinate limburgite, nepheline basalt, basanite, and leucite vicoite. In central to north-central Manchuria there are many recent small cones of leucite basanite (OGURA and others, 1936, 1938, 1939). The average compositions of the common rocks of this region are given in Table 2. As compared with those of the Izu-Hakone P series the rocks have higher alkalies, especially K_2O, and higher TiO_2, P_2O_5, and H_2O.

The volcanoes which lie between these two regions and are included within the main volcanic zone extending from the Kurile Islands, passing through Hokkaidō, Honsyū, and Kyūsyū, to the Ryūkyū Islands are characterized by the calc-alkali or H series. However, the volcanoes lying within this zone but closer to the Pacific coast are made up of both the calc-alkali and tholeiite series, whereas in the volcanoes near the Japan Sea coast of northeastern Honsyū and Hokkaidō the calc-alkali rocks are associated with alkali olivine basalt. The occurrence of this type of basalt together with the calc-alkali series is also seen in a volcano south of Ontake Volcano (15 of Fig. 5) and in Sukumo-yama Volcano (18 of Fig. 5), north Izu Peninsula (Kuno, 1954) lying to the west of the tholeiitic Izu Islands.

Chemical compositions of the tholeiitic basalts and mafic andesites associated with the calc-alkali series in the volcanoes closer to the Pacific coast are listed in Table 12, and

Table 12. - Compositions of tholeiitic basalts and mafic andesites associated with calc-alkali series.

	1.	2.	3.	4.	5.	6.
SiO_2	52.78	53.46	50.79	52.29	47.33	50.73
Al_2O_3	19.01	18.99	17.74	17.98	18.50	19.61
Fe_2O_3	2.48	2.75	3.67	3.44	4.47	1.82
FeO	7.15	6.74	7.06	6.46	5.60	6.63
MgO	3.78	3.82	5.38	5.07	7.51	5.32
CaO	11.08	9.79	10.52	10.05	10.78	13.21
Na_2O	2.21	2.47	2.29	1.86	2.00	1.44
K_2O	0.30	0.48	0.28	0.33	0.24	0.31
H_2O+	0.19	0.33	0.73	0.70	1.41	0.25
H_2O-	0.18	0.20	0.60	0.38	1.56	0.21
TiO_2	0.71	1.06	0.78	0.81	0.54	0.93
P_2O_5	0.25	0.32	0.09	—	0.10	0.09
MnO	0.18	0.22	0.14	0.20	0.17	0.20
Total	100.30	100.63	100.07	99.57	100.21	100.75

1. Masyū Volcano (3) (Katsui, 1955).
2. Usu Volcano (5) (Yagi, 1949).
3. Towada Volcano (7) (Kawano, 1939).
4. Nyohō-Akanagi Volcano (11) (Yamasaki, 1954).
5. Hakone Volcano. Analyst, Katsura.
6. Hakone Volcano (Nagashima, 1953).

Table 13. - Compositions of alkali olivine basalts associated with calc-alkali series.

	1.	2.	3.	4.	5.	6.	7.	8.
SiO_2	49.26	49.58	49.60	48.89	49.90	52.42	47.95	48.10
Al_2O_3	17.71	16.88	16.06	15.00	16.05	16.76	16.46	16.68
Fe_2O_3	2.67	4.19	4.05	2.92	5.03	3.59	4.40	3.88
FeO	7.12	5.97	7.10	6.41	5.55	4.42	5.86	7.75
MgO	7.91	5.29	6.12	10.60	7.03	6.42	8.99	8.89
CaO	10.01	10.75	10.86	10.91	10.51	8.18	10.46	10.48
Na_2O	3.08	3.85	2.76	1.95	2.15	2.27	2.72	2.51
K_2O	0.56	0.88	0.86	1.13	1.92	1.40	1.09	0.46
H_2O +	0.36	0.61	0.54	0.64	0.26	2.54	0.37	n. d.
H_2O −	0.17	0.24	0.12	0.12	0.06	1.02	0.28	n. d.
TiO_2	1.25	1.41	1.40	1.02	1.19	0.61	1.09	0.73
P_2O_5	0.19	0.08	0.17	0.05	0.23	0.21	0.41	0.15
MnO	0.05	0.25	0.21	0.25	0.14	0.17	0.21	0.54
Total	100.34	99.98	99.85	99.89	99.92	100.01	100.29	100.17

1, 2, 3. Risiri Volcano (2) (Katsui, 1953).
4, 5. Osima-Ōsima Volcano (6) (Katsui, 1953).
6. Itinomegata maar (8). Analyst, Katsura.
The rock contains abundant xenocrysts derived from granite.
7. Lava plateau south of On-Take Volcano (15). Analyst, Haramura.
8. Sukumo-yama, Izu Peninsula (18) (Kuno, 1954).

those of the alkali olivine basalts associated with the calc-alkali series in the volcanoes of central to northern Japan are listed in Table 13. All the rocks of Table 12 are poor in alkalies and bear normative quartz, whereas those of Table 13 are rich in alkalies, especially K_2O, and bear normative olivine except rock No. 6 which contains abundant quartz xenocrysts. These compositions are plotted in the total alkali — SiO_2 diagram (Fig. 6) in which line AB of Fig. 2 is reproduced. The rocks of Tables 12 and 13 lie within the tholeiite field and alkali field respectively. Thus it is certain that the rocks of Table 12 belong to the tholeiite series and those of Table 13 to the alkali series, as is also determined by microscopical observation.

In Fig. 5, broken lines AB and CD represent the boundary between the regions where the tholeiite series occur with or without the calc-alkali series and the region where the alkali rock series occur with or without the calc-alkali series.

In Fig. 7 the alkali-lime indices listed in Tables 5, 6, 9, and 10 are indicated as the locations of the corresponding volcanoes. There is a distinct tendency for the volcanoes with lower indices to lie closer to the Pacific coast of the Japanese Islands. Boundary lines AB and CD which are reproduced from Fig. 5 approximately separate the region where the indices are higher than 15 from the regions where the indices are lower than 14 though with a few exceptions.

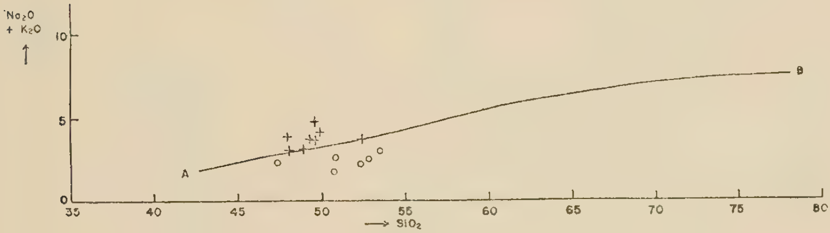


Fig. 6. - Total alkali — SiO_2 relation in the tholeiitic basalt and mafic andesite (open circles) and the alkali olivine basalt (crosses), both associated with the calc-alkali series.

From these facts it is concluded that lines AB and CD of Fig. 5 separate the province below which the parental tholeiite magma is produced from the province below which the parental alkali olivine basalt magma is produced, and that the two provinces are superposed along their junction by the province below which the parental magmas are contaminated by sialic material to form the calc-alkali magmas. The first two are primary provinces and the last one a secondary province. This relation is illustrated by Fig. 8.

The boundary between the two primary provinces and also the outer limits of the secondary province cannot be sharply defined. Probably there are narrow overlapping zones between the two primary provinces. The existence of a complete gradation from the area exclusively of the tholeiite

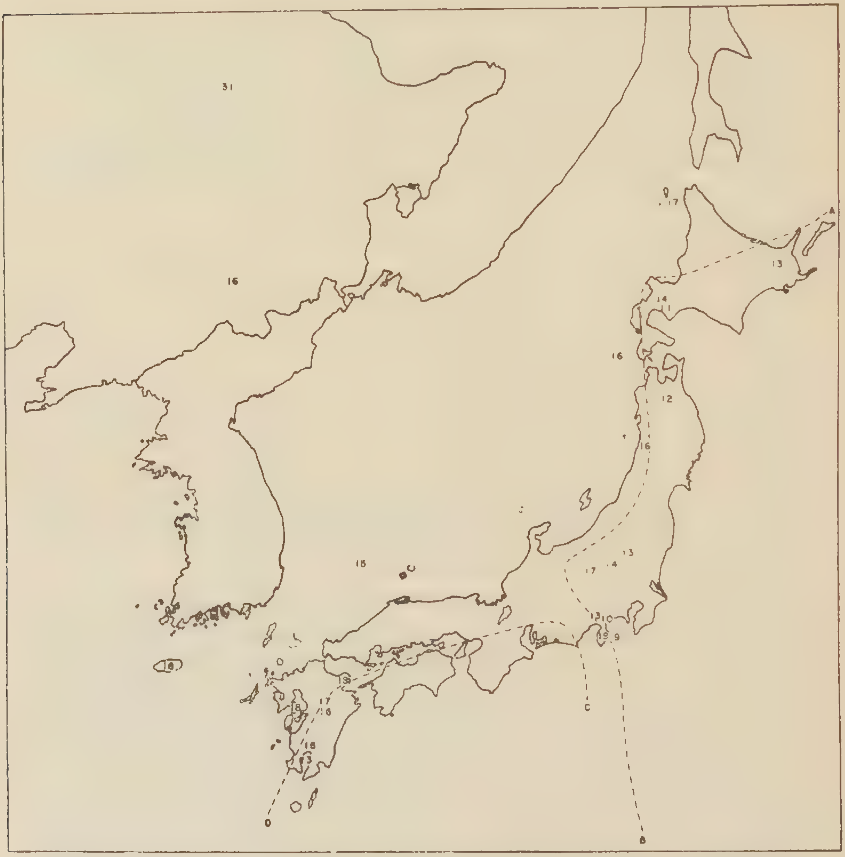


Fig. 7. - The proposed alkali-lime indices for some Quaternary volcanoes.

series to that exclusively of the calc-alkali series has been demonstrated by the gradual change of the abundance of the tholeiitic rocks relative to that of the calc-alkali rocks in the volcanoes lying near the boundary of the two areas in central Japan (Kuno, 1953 c).

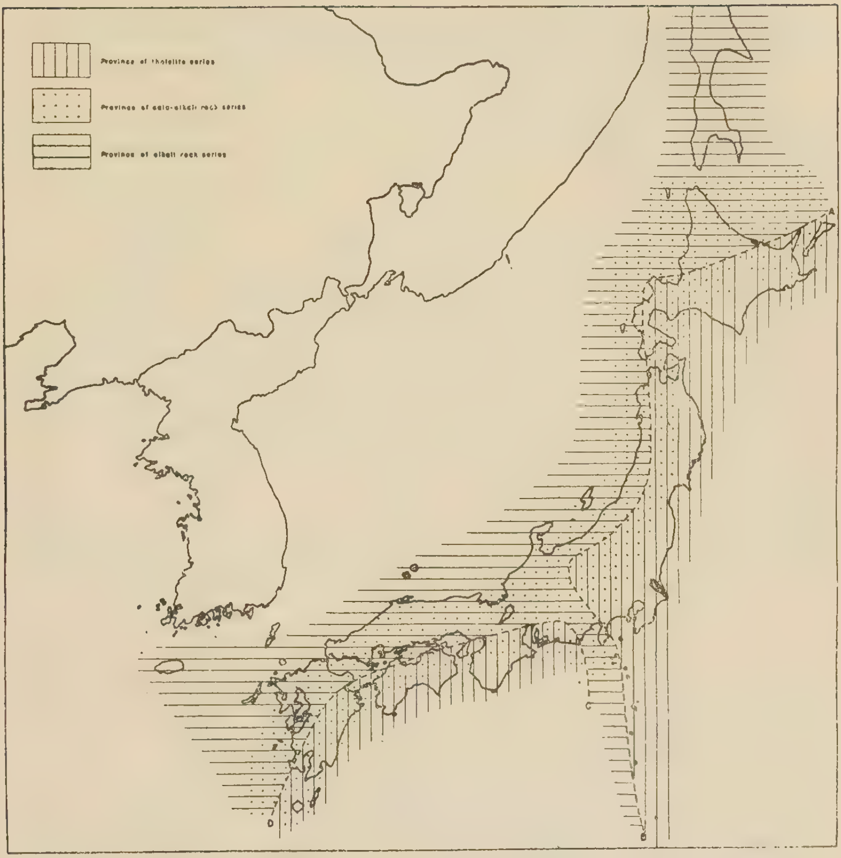

Province of tholeiite series
Province of calc-alkali rock series
Province of alkali rock series
A
D

Fig. 8. - Configuration of the petrographic provinces.

Tertiary petrographic provinces

Distribution of the different rock series through the Miocene and Pliocene volcanic fields is not as well known as in the Quaternary volcanoes. Moreover, in some Tertiary volcanic fields, such as the Sidara (Shidara) Basin (Fig. 9), the tholeiite and alkali series were erupted almost simultaneously.

In Fig. 9 the localities of the Tertiary tholeiite and alkali series are shown. Lines AB and CD of Fig. 5 are again reproduced. Although there are a few exceptions, these lines separate the localities of the tholeiite series from those of the alkali series. Thus the boundary between the two primary provinces appears to have existed also during the Tertiary period approximately at the same position as it is to-day, although it may have shifted slightly from time to time. The calc-alkali province appears to have covered approximately the same area as that shown in Fig. 8.

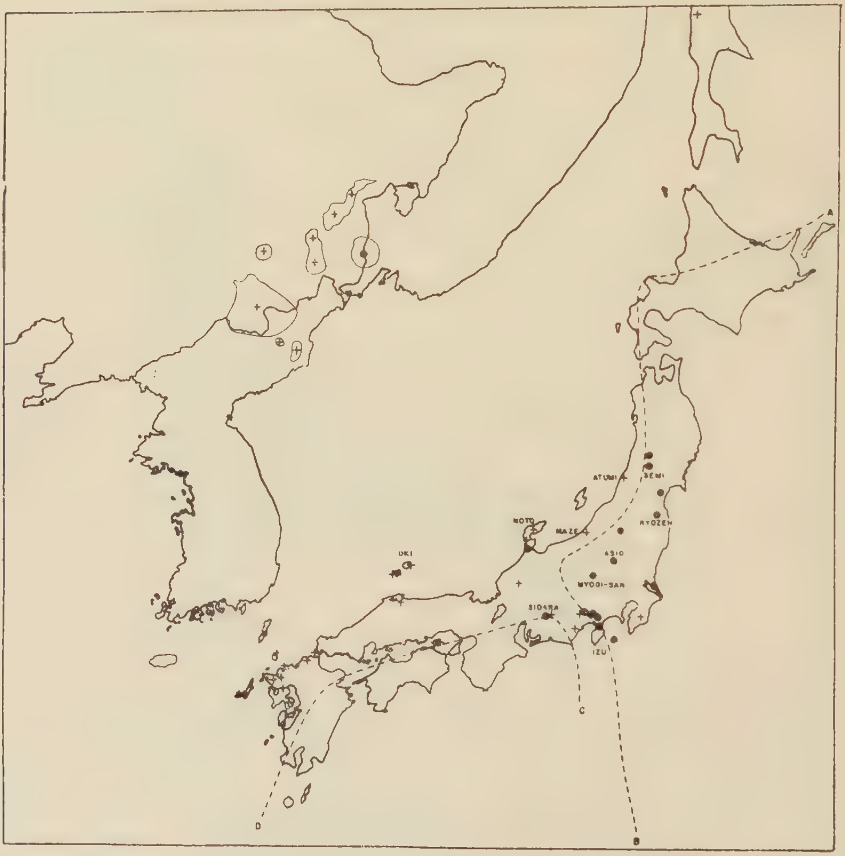


Fig. 9. - Localities of the Miocene and Pliocene tholeiite series (solid circles) and alkali series (crosses).

Crustal structure of Japanese Islands and origin of the petrographic provinces

The configuration of the petrographic provinces appears to be closely related with the crustal structure as deduced from geophysical data.

According to C. Tsuboi's (1954) detailed study of gravity, the Bouguer anomaly has high positive values at various places along the Pacific coast of the Japanese Islands, especially northeastern Honsyū, and gradually becomes lower toward the Japan Sea coast, although there are some irregularities. This fact indicates that a crustal layer consisting of lighter materials becomes generally thinner toward the Pacific coast. The positive anomaly in the Izu Islands is about 100 to 200 mgals, suggesting a structure close to that of the oceanic basin.

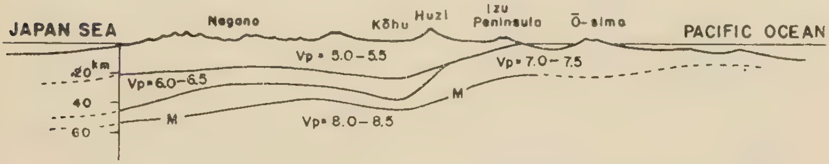


Fig. 10. - Crustal structure along an NW - SE section through central Japan, based on data by Tamaki. The compressional wave velocity for each layer is shown. The horizontal and vertical scales are the same. The surface relief is much exaggerated.

The crustal structure as inferred by Tamaki (1955) from the compressional wave velocities of natural earthquakes agrees generally with the results of the gravity measurements. Fig. 10 is a NW-SE cross-section through central Japan constructed by the writer on the basis of Tamaki's data (the data slightly revised, oral communication). It is seen from the figure that the granitic layer (Vp = 5.0-5.5) is lacking in the Izu Peninsula but appears to the north of the peninsula and becomes thick in the area from the middle of Honsyū to the Japan Sea. The Izu Peninsula is directly underlain by the basaltic layer (Vp = 7.0-7.5) which continues downward to the M discontinuity lying at a depth of about 20 km. It is very likely that the Izu Islands, except the rhyolite islands of Nii-zima, Sikine-sima, and Kōzu-sima just south of the peninsula, are also underlain directly by the basaltic layer as in the Pacific Ocean, as is suggested by the gravity anomaly. DIETZ (1954) believes that the Izu - Mariana Arc represents an oceanic ridge.

However, as fragments of granitic rocks are sometimes found in lavas and pyroclastic rocks of the peninsula (KUNO, 1954) and also of Nii-zima (TSUYA, 1938), the granitic material is present sporadically underneath the peninsula and extends to the base of the Kōzu-sima, 50 km south of the peninsula. Such fragments have not been observed in the tholeiitic Izu Islands.

It is concluded that the parental tholeiite magma is generated within the peridotite layer below the Izu Islands and the northern part of the Izu Peninsula and undergoes simple fractional crystallization before eruption to the surface, resulting in the volcanoes made up exclusively of the tholeiite series. In the other part of the primary tholeiite province, the same parental magma is also produced, but during its passage through the granitic layer, it may or may not be contaminated by this material. Both the parental and contaminated magmas undergo fractional crystallization and erupt to the surface to form the volcanoes of the tholeiite and calc-alkali series (the tholeiite province superposed by the calc-alkali province).

The writer agrees with MACDONALD's (1956) statement that the presence of the P series does not in itself indicate the absence of the sialic crust; it occurs in both the oceanic and continental regions.

In the alkali province, the parental alkali olivine basalt magma is produced within the peridotite layer. Although in the Japan Sea area, Korea, and Manchuria, the magma should pass through the thick granitic layer, it is not contaminated by this material but undergoes simple fractional crystallization and erupts to the surface to form the volcanoes made up exclusively of the alkali series. In the other part of the primary alkali province, the contamination and fractional crystallization of the parental magma take place, giving rise to the volcanoes made up of the alkali and calc-alkali series (the alkali province superposed by the calc-alkali province). YAGI believes (oral communication) that the alkali rhyolite occurring in the Oki Islands in the Japan Sea and Hakutō-san Volcano on the Manchuria-Korea boundary, is a product of contamination of the alkali magma. Slight contamination may take place even outside the calc-alkali province.

The Japan Sea area, Korea, and Manchuria have been relatively stable since early Tertiary and have been subjected only to block movements. Such circumstance would not favor the contamination. The calc-alkali province corresponds approximately to a zone of intense folding and faulting that started in middle Tertiary and are still going on. In this orogenic zone, the parental magmas may have been kneaded with the granitic material or may have easily engulfed the intensely fractured wall rocks of the reservoir.

A question arises as to why the tholeiite magma is generated on the Pacific side of the Japanese Islands and the alkali olivine basalt magma on the Japan Sea side, and in the narrow zone traversing central Japan.

The configuration of the tholeiite and alkali provinces appears to have a close connection with the distribution of the intermediate to deep earthquake foci first discovered by WADATI. According to WADATI and IWAI (1954), the foci of these earthquakes are distributed as shown in Fig. 11. Boundary lines are drawn by the writer so as to separate the areas for the earthquake foci 50 to 200 km deep and the area for deeper ones. These lines are located very closely to the boundary lines between the tholeiite and alkali provinces. This fact is too striking to be overlooked. A close connection appears to exist between the mechanism of magma production and that of earthquake generation. It is suggested that the parental magmas are produced at the foci of the earthquakes which are distributed in the pattern demonstrated by WADATI

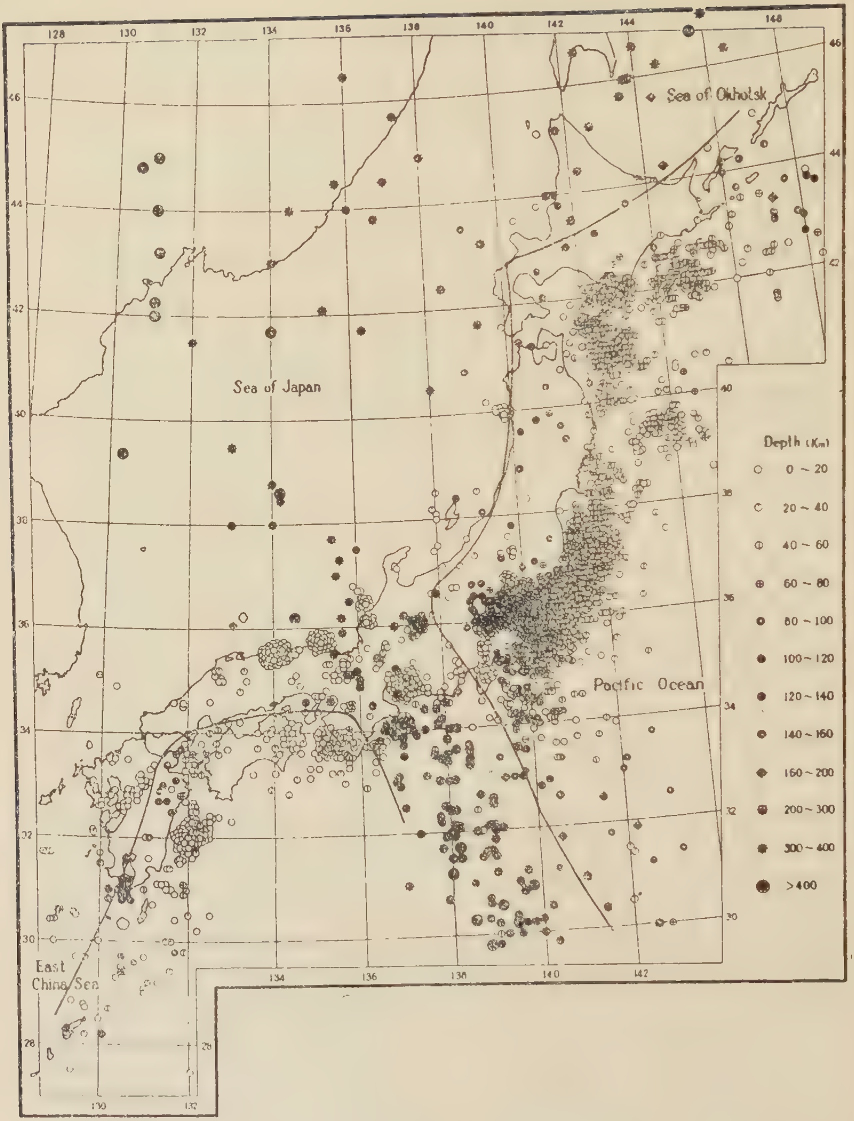


Fig. 11. - Distribution of epicenters of earthquakes which occurred from 1926 to 1953. The depths of the foci are indicated by different marks. Reproduced by the permission of Dr. K. Wadati. The lines are drawn by Kuno to show the boundary between the areas for earthquakes shallower than 200 km and those deeper than that level.

and IWAI. The observed correspondence between the lines separating the areas for the earthquakes of different depths and the boundary lines of the primary provinces would imply that the tholeiite magma is produced at depths shallower than 200 km whereas the alkali olivine basalt magma at deeper levels.

The same relation as regard to the relative depths for the production of the two types of magma has been suggested from the study of the Hawaiian basalts (KUNO and others, 1957).

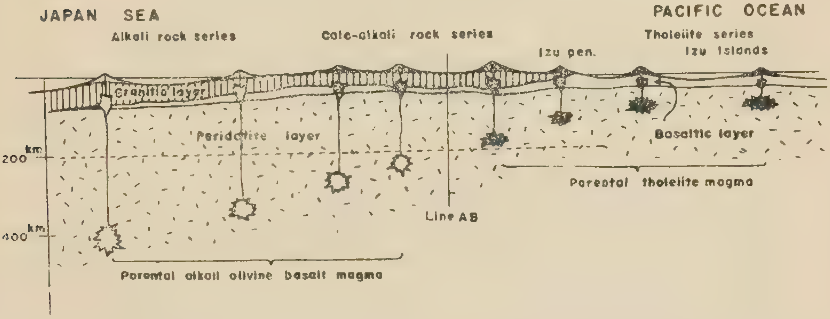


Fig. 12. - Schematic profile section across central Japan, showing the source of the parental magmas and the places where the contamination by the granitic material takes place. Black areas: — the parental tholeiite magma and its fractionation products; white areas: — the parental alkali olivine basalt magma and its fractionation products; dotted areas: — the contamination products (the calc-alkali series). The horizontal scale is exaggerated.

The idea stated above is schematically shown in Fig. 12 which represents a cross section through central Japan (compare with Fig. 10). A vertical line is drawn from the point where line AB of Fig. 5 meets the cross section.

A hypothesis proposed by MATUZAWA (1953, 1954) is important in this connection. He states that shallow earthquakes of great magnitude and intermediate to deep earthquakes are caused by the expansion force generated when solid rocks melt to form magmas. Some of the shallow earthquakes may be caused by different mechanisms. AKI (1954) believes that the heat necessary for the melting is supplied from below by convection currents within the peridotite layer.

The distribution pattern of the intermediate to deep earthquakes in other parts of the Circum-Pacific zone of folding is generally similar to that found in the Japanese Islands. We must investigate whether the correspondence between this earthquake pattern and the distribution of primary tholeiite and alkali provinces also applies to the other parts of this zone.

REFERENCES

(Papers quoted only in the text are listed below)

AKI, K., 1954: *Thermal processes near the earth's crust.* Zisin, ser. 2, 7, 65 - 76 (in Japanese).

BAILEY, E. B. and others, 1924: *Tertiary and post-Tertiary geology of Mull, Loch Alin, and Oban.* Mem. Geol. Surv. Scotland, 13-33.

BANDY, M. C., 1937: *Geology and petrology of Easter Island.* Bull. Geol. Soc. Am., 48, 1589 - 1609.

BARTH, T. F. W., 1942: *Lavas of Gough Island.* Sci. Result of Norwegian Ant. Exp. 1927 - 28, No. 20, Det. Norske Vid.-Akad. i Oslo, 3 - 19.

BARTH, T. F. W. and HOLMSEN, P., 1939: *Rocks from the Antarctandes and the Southern Antilles.* Sci. Result of Norwegian Ant. Exp. 1927 - 1928, No. 18, Det. Norske Vid.-Akad. i Oslo, 7 - 64.

DIETZ, R. S., 1954: *Marine geology of northwestern Pacific: Description of Japanese bathymetric chart 6901.* Bull. Geol. Soc. Am., 65, 1199 - 1224.

HENDERSON, J. and GRANGE, L. I., 1926: *The geology of the Hantly-Kawhia Subdivision, Paroigia and Hauraki Divisions.* N. Z. Geol. Surv. Bull. 28 (new series).

HOLMES, A., 1921: *Petrographic methods and calculations, Part III.* Thomas Marby and Co., 452 - 454.

HOTZ, P. E., 1953: *Petrology of granophyre in diabase near Dillsburg, Pennsylvania.* Bull. Geol. Soc. Am., 64, 675 - 704.

KATSUI, Y., 1953: *Petro-chemical study on the lavas from Volcano Rishiri, Hokkaido.* Japan Jour. Fac. Sci. Hokkaido Univ., ser. IV, Geol. Miner., 8, No. 3, 245 - 258.

——— 1954: *Chemical compositions of lavas of Tyōkai volcanic zone.* Jour. Geol. Soc. Japan, 60, 185 - 191 (in Japanese).

——— 1955: *Geology and petrology of the Volcano Mashū, Hok-*

kaido, Japan. Jour. Geol. Soc. Japan, 61, 481 - 495 (in Japanese).

KENNEDY, W. Q., 1933: *Trends of differentiation in basaltic magmas.* Am. Jour. Sci., 25, 31 - 47.

KOTO, B., 1916: *On the volcanoes of Japan.* Jour. Geol. Soc. Tokyo, 23, 1 - 13, 17 - 28, 29 - 55, 77 - 94, 95 - 127.

KŌZU, S., 1911: *Preliminary notes on some igneous rocks of Japan.* Jour. Geol., 19, 555 - 560, 566 - 575.

——— 1912: *Preliminary notes on some igneous rocks of Japan.* Jour. Geol., 20, 656 - 665.

——— 1913: *Preliminary notes on some igneous rocks of Japan.* Jour. Geol., 21, 62 - 67.

KUNO, H., 1950: *Petrology of Hakone Volcano and adjacent areas, Japan.* Bull. Geol. Soc. Am., 61, 957 - 1020.

——— 1952: *Cenozoic volcanic activity in Japan and surrounding areas.* Tr. New York Acad. Sci., 14, 225 - 231.

——— 1953 a: *Formation of calderas and magmatic evolution.* Tr. Am. Geoph. Union, 34, 267 - 280.

——— 1953 b: *Plateau basalt lavas of East Manchuria.* Proc. 7th Pacific Sci. Cong., New Zealand, 2, 375 - 382.

——— 1953 c: *Volcanoes and volcanic rocks.* Iwanami-Zensyo, 180 - 181 (in Japanese).

——— 1954: *Geology and petrology of Ōmuro-yama Volcano Group, Izu Peninsula.* Jour. Fac. Sci., Univ. Tokyo, Sect. II, 9, 241 - 265.

KUNO, H., YAMASAKI, K., IIDA, C., and NAGASHIMA, K., 1957: *Differentiation of Hawaiian magmas.* Jap. Jour. Geol. Geogr., (in press).

MACDONALD, G. A., 1949: *Hawaiian petrographic province.* Bull. Geol. Soc. Am., 60, 1541 - 1596.

——— 1956: *The structure of Hawaiian volcanoes.* Verh. Konin. Neder. Geol. Mijn. Geno., 16, 1 - 22.

MATUZAWA, T., 1953: *Feldtheorie der Erdbeben.* Bull. Earthq. Res. Inst., 31, 179 - 201.

——— 1954: *Feldtheorie der Erdbeben : Näheres über das Quellengebiet.* Bull. Earthq. Res. Inst., 32, 341 - 347.

OGURA, T., MATSUDA, K., NAKAGAWA, T., MATSUMOTO, M. and MURATA, K., 1936: *Volcanoes of the Wu-ta-lien-chih district, Lung-chiang Province, Manchuria.* Survey Rep. of Volcanoes of Manchuria, Ryojun Coll. Engineering, No. 1, 1 - 96 (in Japanese).

OGURA, T. and MATSUMOTO, M., 1938: *Erh-ko-shan Volcano, Lung-chiang Province, Manchuria.* Survey Rep. of Volcanoes of Manchuria, Ryojun Coll. Engineering, No. 2, 1 - 21 (in Japanese).

OGURA, T., SAWATARI, M. and MURAYAMA, K., 1939: *Chi-hsing-shan Volcano, Feng-tien and South Hsing-an Provinces, Manchuria.* Survey Rep. of Volcanoes of Manchuria, Ryojun Coll. of Engineering, No. 3, 1 - 44 (in Japanese).

PEACOCK, M. A., 1931: *Classification of igneous rock series.* Jour. Geol., 39, 54 - 67.

POLDERVAART, A., 1944: *The petrology of the Elephant's Head dike and the New Amalfi sheet (Matatiele).* Tr. Roy. Soc. S. Africa, 30, 85 - 119.

TAMAKI, I., 1955: *The crustal structure of Japan derived from observed travel time curves of shallow earthquakes.* Zisin, ser. 2. 7. 1 - 7 (in Japanese).

TANEDA, S., 1951: *Studies on the volcanoes in Japan - The chemical compositions of the lavas* (1). Rep. Fac. Sci., Kyūsyū Univ., Geology, 3, No. 2, 55 - 75 (in Japanese).

TILLEY, C. E., 1950: *Some aspects of magmatic evolution.* Quart. Jour. Geol. Soc., 106, 37 - 61.

TOMITA, T., 1935: *On the chemical composition of the Cenozoic alkaline suite of the Circum-Japan Sea region.* Jour. Shanghai Sci. Inst., sect. II, 1, 227 - 306.

TSUBOI, C., 1954: *Gravity survey along the lines of precise levels throughout Japan by means of a Wordon gravimeter, a chart attached to* Bull. Earthq. Res. Inst., 4, Suppl.

TSUYA, H., 1937: *On the volcanism of the Huzi Volcanic Zone, with special reference to the geology and petrology of Idu and the Southern Islands.* Bull. Earthq. Res. Inst., 15, 215 - 357.

——— 1938: *Volcanoes of Nii-zima, Seven Izu Islands.* Bull. Earthq. Res. Inst., 16, 171 - 200 (in Japanese).

WADATI, K. and IWAI, Y., 1954: *The minute investigation of seismicity in Japan.* Geoph. Mag., 25, 167 - 173.

WAGER, L. R. and DEER, W. A., 1939: *Geological investigations in East Greenland. Petrology of the Skaergaard intrusion, Kangerdlugssuaq, East Greenland.* Med. om Grønland, 105, No. 4, 1 - 352.

WALKER, F., 1940: *Differentiation of the Palisade diabase, New Jersey.* Bull. Geol. Soc. Am., 51, 1059 - 1106.

WALKER, F. and NICOLAYSEN, L. O., 1954: *The petrography of Mauritius.* Colonial Geol. Miner. Res., 4, 3 - 43.

WALKER, F. and POLDERVAART, A., 1949: *Karroo dolerites of the Union of South Africa.* Bull. Geol. Soc. Am., 60, 591 - 706.

Academy of sciences of the USSR
THE NATIONAL COMMITTEE FOR GEODESY
AND GEOPHYSICS
Section of volcanology

G. S. GORSHKOV

Gigantic eruption of the Volcano Bezymianny

(With 39 plates)

Introduction

On October 22, 1955, after a three week swarm of earthquakes, for the first time in history a lengthy eruption of Bezymianny volcano had started. This volcano is located in the very centre of the famous Kliuchevskaia group of volcanoes in Kamchatka. Its absolute height before the eruption was 3085 m, relative height over the base level - from 700 m in the North up to 1200 m in the South. Geographical position of the crater: 55°58′ North; 160°35′ East. North of Bezymianny rises a ruined cone of volcano Kamen (4585 m), behind it - Kliuchevskaia sopka (4750 m); to the South of Bezymianny a mass of Zimina sopkas (3081 m) is found (fig. 1).

Until recently Bezymianny volcano was not much studied. According to preliminary data it consists of a complex mass, the southeastern part of which consists of a large extrusive dome, and its western part - of a younger strato volcano. Before the eruption we are describing, there was an ill-defined crater on the summit about 500 m in diameter, which has been practically completely filled by an internal cone with a sealed crater of approximately 200 m in diameter. From the western rim of the outer crater a deep gorge was descending; a second gorge was coming down eastwardly and gave birth to one of the heads of the river Sukhaia (Dry) Hapitsa (fig. 2).

Judging by the shape of the volcano its history must have been rather complicated: during the first phase of volcanism a big dome was formed, which could have grown in the crater of an old strato volcano. As turning point served the formation of the young strato volcano. This moment was preceded, apparently, by a lengthy period of repose. As the original vent proved to be plugged by a lava plug of the dome, the new eruptive centre shifted somewhat to the West and the strato volcano was formed in the marginal part of the dome, which was partly overlain by young lavas. The strato volcano displayed a mixed type of activity; a complicating feature was the formation of a number of smaller lateral domes. The final stage in the life of the volcano was marked by the formation of a small internal cone in the crater. After that a lengthy period of dormancy began. The second turning point was the eruption of 1955-1956. the description of which we will give below.

Course of the eruption

To make the description easier the process of eruption could be divided into the following five stages:

1. Pre-eruptive stage, which includes the period from the first volcanic earthquake until the day preceding the first gas outburst of the volcano, namely from September 29 up to October 21, 1955.

2. Stage of strong ash eruptions of Vulcanian type - beginning with October 22nd until the end of November, 1955.

3. Stage of a moderate activity - from December, 1955 until March 29, 1956.

4. Gigantic paroxysmal explosion on March 30, 1956.

5. Growth and development of an extrusive dome in the newly formed crater - beginning with April and up to late in the autumn of 1956.

The total length of the eruption is slightly over a year.

The eruption took place in the eastern part of the volcano, unseen from the neighbouring villages. Observations of the process of eruption had to be carried out from an uninhabited region in the upper reaches of the river Sukhaia Hapitsa. All the main volcanic phenomena took place during the winter of 1955-56. Severe winter conditions were made even harder by a frequent and lengthy recurrence of bad weather; of additional difficulty were ashfalls, which greatly hampered the use of dog-driven sledges - the only possible kind of transport in snowy Kamchatka winter conditions. In spring the road was blocked for our expeditions by extremely violent torrents streaming down from the mountains; *) in summer we were suffering from lack of potable water and our horses from the lack of grass buried under a thick layer of ash. In such difficult and sometimes even dangerous conditions constant observations were impossible and we did not succeed always to see everything we wanted with sufficient completeness.

1) Pre-eruptive stage

The eruption was preceded by a swarm of numerous earthquakes. Their total number before the beginning of the eruption was 1285.

The first shock of this swarm was registered on September 29, 1955, the displacement came to 11 μ. One shock every day was registered beginning with October 2nd until October 5th, there have been four of them on October 6th, five on the 7th; on October 8th the number of earthquakes exceeded ten; beginning with October 9, earthquakes were counted by dozens a day and beginning with October 12, - already 100-200 a day. On October 11th the displacement of the ground in Kliuchi exceeded 100μ, the epicentre was determined for the first time (volcano Bezymianny region) and its depth (about 50 km). Beginning with October 18, there have been shocks with an amplitude of 1000μ and more. However, owing to a considerable period of the maximum phase, shocks in Kliuchi, where registration was taking place, were not felt and were only recorded by seismographs.

---

*) Under a layer of ash the melting of glaciers in spring of 1956 was especially intense.

The character of this swarm of earthquakes permitted us with a considerable degree of certitude to expect the eruption at an early date. Epicentres of the earthquakes were falling on the area of Bezymianny volcano, which was regarded as extinct. This left a shade of doubt that the eruption will take place from this volcano. It could sooner be suggested that a new lateral crater will burst out near the southern base of Kliuchevsky volcano. And yet this time seismic data gave an absolutely exact forecast of the point of eruption.

2) Stage of strong ash eruptions

The eruption began about 6.30 in the morning of October 22nd. At this time white puffs of an eruptive cloud appeared beyond the eastern flank of Kliuchevskaia sopka and could be seen from Kliuchi. Immediately after the first gas outburst emission of ashes began.

During the first days the eruption was of a moderate character; the height of the ash-gas cloud did not exceed 1-2 km above the crater. However, its intensity grew day after day. Beginning with October 26th ashfalls of growing intensity were taking place in a radius of 40-60 km from the volcano. For instance on November 1-3 all works in the streets of village Kozyrevsk (45 km West of the volcano) had to be stopped because of the ashfall. Weak ashfalls were taking place at a distance up to 120-130 km from Bezymianny (village Esso in Sredinny (Midle) mountain range - 120 km West of the volcano, village Ust-Kamchatsk on the coast of Pacific ocean at the same distance ENE of the volcano). In the village Kliuchi — 45 km NNE from Bezymianny — by November 9th a layer of ashes had fallen 6 mm thick or 3.5 kg/m^2. In the region of our expeditionary camps 1 and 2 the layer of ashes on the snow at this time reached 3-4 cm.

The column of ashes was bursting out of the new crater, which was formed somewhat below the summit of the volcanic mass, on the boundary between the old dome and the young strato volcano. Apparently the vent of the strato volcano also got plugged up completely, so that the zone of least resistance proved to be the boundary between the two old vents and here a new channel had passed. (The question stands, naturally, only about the upper part of the channels) (figs. 3 and 4).

Judging by the thickness of the ash jet, the diameter of the new crater did not exceed 250 m. The first 160 m were passed by the ash cloud in 3 seconds, i.e. with an average velocity of 50 m/sec. At the very crater the puffs of ashes were literally boiling.

On November 7th the eruption obviously intensified. In camp No 2, 12 km from the volcano, deafening roars of explosions were heard, the rumbling spreading also on the ground. In the morning of November 7th a layer of ashes had fallen 10 mm thick. From the roof of the tent ashes had to be shovelled off (fig. 5).

On November 13th the height of the ash cloud over the crater reached 5 km. All night enormous bright lightnings were flashing through the eruptive cloud; sometimes they were globe lightnings, but mostly linear. Lightnings were flashing mainly aside from the crater and mostly on the lower margin of the eruptive cloud (fig. 6). The ashcloud was drifting eastwards, the ashfall was reaching the coast of the Pacific ocean and departing further into the open sea. On November 14th the height of the ash column reached 7.5 km over the crater (10.5 km above sea level) and on November 16-20 heavy ashfalls took place in Kliuchy. On November 17th it was dusk all day through, light was burning in the houses and on the streets, automobiles had their headlights switched on. All work in the street had to be stopped. Sometimes the ashfall was so heavy that lighted windows and street lanterns could not be seen at a distance of 150-200 m. During the period from November 16 up to November 21 a layer of ashes in Kliuchy came to 16.6 mm, which is 10.9 kg/m². 70 % of this amount fell during twenty four hours of November 16th and 17th. From the biginning of the eruption to the end of November the total sum of the ashes in Kliuchy amounted to 25 mm, which is about 16 kg/m². During these days ashes fell in a wide stretch going North from the volcano to a distance up to 250 km (fig. 7).

In November explosions considerably enlarged the crater. Now it had a diameter of 700-800 m and, being slightly elongated in the latitudinal direction, was embracing part of the summit of the old dome and the internal cone of the strato volcano.

3) Stage of moderate activity

Beginning with the end of November, 1955 the intensity of the eruption began to fall and by the end of December the volcano started on its phase of moderate activity, which lasted until March 29, 1956.

During this period ash eruptions became rarer and much weaker: the height of the ash and gas cloud, as a rule, did not exceed 1-1.5 km over the crater. From time to time in a radius up to 50-60 km ashes would fall, but now ashfalls got much weaker than before. So in Kliuchi, for instance, ashes were falling at a quantity of 10-20 g/m^2, instead of kilograms as in the preceding period. More often dense snow-white puffs of fumarolic gases would rise from the crater to a height of 1-2 km, but they would not contain any admixture of ashes.

On January 25, 1956 it became possible to observe the crater of the volcano more detailedly from an airplane (fig. 8). Against our expectations, the depth of the crater proved to be not great. The bottom of the crater looked like a sloping, convex shield and was covered by pyroclastic material, from underneath of which sharp spurs of dark lava were protruding in two or three places. Apparently, following the explosions of November, 1956, which widened the crater, there began to grow a dome. Its surface was littered by ejectamenta of weak explosions which took place from time to time on the margins of the dome at a boundary between the dome and the vent. Two eruptive boccas could be distinguished, from which thick wreathes of steam and gases were exhaled. Weaker fumarolic jets were rising in many places along the periphery of crater. There have been, however, no fumaroles in the middle part of the crater (fig. 9).

The growth of the intercrateral dome was accompanied by shoves on the southeastern flank of the volcano and now the old dome was standing out quite clearly and its boundary with the strato volcano became very distinct (figs. 10-11). Especially noticeable were movements on the very boundary, where a cliff was protruded, speckled with hundreds of powerful fumaroles and covered with multicoloured sublimates.

Early in February the volcano could have been observed from our camps 1 and 2. In the southern part of the crater often, though weak, explosions were taking place which gave birth to minor incandescent avalanches. Sometimes stronger explosions happened, raising columns of ashes to a height of 2-3 km above the crater and accompanied by more powerful avalanches (fig. 12). One of these avalanches on February 9th reached the foot of the volcano in 50 seconds, the velocity of this glowing stream being about 50-60 m/sec or about 200 km/h on a grade of 35°.

Upon comparison of photographs taken at this time (fig. 13) with earlier pictures one could see that in the SE part of the volcano not only local shifts were taking place but that a general uplift of the old dome, which composed this part of the volcanic mass, also occurred. The magnitude of the uplift was determined as approximating 100 m. The new line of the flank perceptibly shifted to the SE and the volcano as if was widened. Fig. 14 gives new outlines on the background of old ones; we can see that the striking widening of the summit was determined not only by an increase of the crater, but to a considerable degree (by 230 m) also by the growth of the old dome.

The steepness of this part of the flank obviously increased - from 30 to 35°. The upper 300 m were built of the massive body of the dome and the lower part by a loose agglomerate, the formation of new portions of which was accompanying the shift of the old dome. Fresh « breccia crust » [*]) completely covered up a considerable part of the eastern gorge.

The resumption of the growth of the old dome after a period of repose during several hundreds of years, and maybe even longer, was an exceptional fact and was an evidence of an exceptionally high magmatic pressure which could not find an outlet in the squeezing out of one intercrateral plug alone.

4) Paroxysmal explosion of March 30, 1956

On March 30, 1956 a turning stage occurred in the process of eruption. On that day a tremendous explosion took place which destroyed the top of the volcano and completely changed not only its shape but even the relief of the surrounding terrain.

The day was very clear and the eruption could be observed, in that or other form, from all surrounding villages. At the moment of the eruption a rather strong volcanic earthquake took place, the time at the focus of which — 17 h. 11 m. 05 sec. — corresponds, apparently, to the beginning of the explosion. This time is well in accord with the time determined by the velocity of propagation of the blast, registered by barographs of many meteorological stations.

Line fitter V. P. Sorokin from the village Kamaki (65 km NE from the volcano) was the first who noticed the eruption. Being at home he felt a « pressure in his ears », i.e. a sharp change in the atmospheric pressure and immediately understood that something happened at the volcano. Running out of the house, he saw above Bezymianny volcano an obliquely directed eruptive column (about 30° to the horizon and in an eastward direction), which was impregnated by sparks and looked like one consisting of fire [**]) (judging by the velocity of propagation of the blast, it must have been 3-4 minutes after the beginning of the eruption). Above this « fiery spout », also in an oblique way, about 45° towards the horizon, puffs of « smoke » were rapidly growing and in 1-2 minutes hid the tops of all the volcanoes. 4-5 minutes later light vapours began to rise along the valley of the river Sukhaia (Dry) Hapitsa and at the southeastern foot of Kliuchevskaia sopka. In Hapitsa valley they seemed to be rolling in waves and were accompanied by « sparks » (these were agglomerate streams). Soon a dense, black eruptive cloud with a powerful ashfall, moving towards the observer, hid the following course of events. It is interesting to point out that the sharp change in pressure resulting in an unpleasant feeling in the ears was noticed by many villagers in Kamaki; unfortunately there is no meteorological station here and the magnitude of the baric wave remained undetermined.

---

[*]) Brèches d'écroulement.

[**]) Apparently all light effects were connected with the sunset.

The most favorable conditions for observations were in Kozyrevsk: the sun was setting and illuminating the entire picture of the eruption and a SW wind in the higher layers of the atmosphere was drifting the ashcloud away from Kozyrevsk leaving the volcano open. The eruptive cloud quickly expanded in fan-like shape sidewise and upwards. The lower edge of the gigantic « fan » was at a height of 6-8 km, while the upper - at about 35 km. The giants of Kliuchevskaia group of volcanoes seemed insignificant in comparison with this formidable and awe inspiring volcanic cloud (fig. 15). At the moment of the eruption all sopkas were clear, but then rapidly got enveloped by thick « caps » of atmospheric clouds. The vertical velocity of the cloud's movement was not measured, but all eyewitnesses unanimously noted its swiftness and impetuosity. Fig. 16 shows one of the early moments of the eruption; along with the general majestic picture several important facts should be indicated: 1) explosions did not ruin the western part of the top of the volcano, 2) the explosions were not directed straight upwards, but had a rather strong incline towards the East, 3) at the base of the volcano ashclouds were rising from descending agglomerate streams, one of which was descending into the head of river Studenaia, while the second — a more powerful one — into the valley of Sukhaia (Dry) Hapitsa. The thick ash wall of the latter could be seen also from Kliuchi.

From Ust-Kamchatsk the cloud of the main explosion was well seen, covering the entire western part of the horizon. The cloud itself was impenetrably black, but its light margins, illuminated by the rays of the setting sun, formed a bright golden rim. In 15-20 minutes after the main explosion a narrow gas wedge of one more explosion which could be seen only from here. The end of the eruption was hidden from Ust-Kamchatsk by a curtain of ashfall over Kumroch mountain range.

On negatives of pictures taken from Ust-Kamchatsk the height of the ashcloud could be determined with the greatest precision; the top of the ashcloud reached a height of 34-36 km, and the « wedge » of the following explosion grew for another 8-10 km, i.e. up to about 45 km.

In Kliuchi conditions for observation of the eruption itself were the most unfavourable, but that was the direction in which the ashcloud of the main explosion drifted and here were well seen all the phenomena occurring in the cloud, which rapidly advanced from the South. It was not wide, in the East and West clear sky could be seen. The cloud was curling intensely and quickly changed its outlines, advancing towards the North-East. It seemed to be very thick and almost tangibly heavy. Together with the cloud came also and was growing a rumble of loud thunder accompanying incessantly flashing lightnings. About 5.40 p.m., when the cloud already passed the zenith, ashfall began; the dirty surface of a slightly melted snow was quickly covered by a light-gray coating. At first only separate large particles were falling (up to 3 mm), which rattled against window glass like hail. By 5.40 p.m. the ashfall intensified and by 6.20 p.m. it got so impenetrably dark that one could not see his own hand, even if brought up to the very face. People returning from work were wandering about the village in search of their homes... Peals of thunder were crashing with deafening loudness without any interruption. The air was saturated with electricity, telephones were ringing spontaneously, loudspeakers of the radionet were burning out, sparks were bursting out of antennae inlets of radiosets... There was a strong smell of sulphurous gas. By 9.00 p.m. the ashfall thinned out and patches of starlit sky appeared. During three and a half hours in Kliuchi a layer of ash 20 mm thick had fallen (24.5 kg/m^2).

The ashfall embraced a rather narrow zone in the northeastern direction. In the district of Sheveluch volcano (80 km from Bezymianny), where at that time a group of employees from the Volcanological station was working, the ashfall was just as intense as in Kliuchi. At the moment of eruption people have been in the valley of a mountain river and the ashfall caught them during their ascent to an expeditional cabin. Despite the increasing ashfall the group continued to ascend, but by 6.50 p.m. it got so inky dark, that a tent had to be put up in 300 m from the cabin. This happened in a forest, but the tent had to be stretched on skis, because it was impossible to leave the sledges even for a couple of paces. Just as in Kliuchy, thunder was rumbling incessantly. By 3 a.m. on March 31st the darkness dispersed; a coat of ashes 2 cm thick (22.3 kg/m^2) was covering the snow.

A strong ashfall took place also in the mouth region of river Ozernaia (about 200 km from Bezymianny); in the village Uka (225 km from the volcano) 3 mm of ashes had fallen, and in the environs of village Ossora (400 km NNE from Bezymianny) the ash cover was about 1 mm. The two last points were, apparently, not in the axial part of the ashfall, which, probably, was in the Bering Sea, East of the island Karaginsky. Thus the ashfall occupied a comparatively narrow but long stretch, the width of which hardly reached 100-150 km and length exceeded 400 km *) (fig. 17). The total volume of ashes fallen on this area (40,000 km^2) according to the most modest estimates comes to 0.4-0.5 km^3.

To the West and South of the volcano no ashfall was observed, but there was a strong mist and a noticeable smell of sulphurous gas was felt (at a distance over 100 m from the volcano).

---

*) Thin ashes were caught at height by jet streams, passed over the North Pole and on April 3-4, 1956, a thin cloud of volcanic dust was seen in stratosphere over western Britain (8).

The picture of this explosion was stupendous and greatly exceeded everything ever seen by even oldtimers of Kamchatka and yet the entire might of this eruption could be grasped only after having visited the volcano and studied the consequences of the explosion.

As a result of the explosion the Bezymianny volcano had changed beyond recognition: instead of a regular, slightly truncated cone it became a semi-ring caldera-volcano. The dome in the SE part was fully destroyed and a new tremendous crater was occupying not only the summit, but also the entire SE flank up to its very base. The new crater acquired the shape of a semi-ring 1.5 by 2 km in size, somewhat elongated in a latitudinal direction. The uneven, breached rim of the crater is obliquely truncated towards the SE and has the greatest height in the West, descending in the East to the very basement of the volcano. The highest point of the volcano has decreased by 150-180 m and its absolute height now is about 2900 m instead of 3085 before the eruption. The western gorge on the flank remained, while the eastern got completely included into the new crater (fig. 18).

The valley of the river Sukhaia (Dry) Hapitsa, which begins on the eastern flank of the volcano, was completely littered at a distance of 18 km by a powerful agglomerate flow consisting of a chaotic mixture of ashes, sand and lava blocks. Many thousands of secondary fumaroles were rising from the surface of the flow.

The territory surrounding the volcano from the East at a distance of 10-13 km was covered by a coat of sand up to 0.5 m thick. Further eastwards at a distance up to 27-29 km the thickness of sand and cinder rapidly decreased up to several centimeters. Ashes were not falling quietly from above, but were breaking out of the crater with a colossal force like a jet of some gigantic sandblast apparatus. Our cabin, located in 12 km from the volcano, was literally « blown off », not a single board remained. At a distance of 25-30 km from the crater trunks of trees and bushes on the side facing the volcano were stripped bare; on the opposite side the bark was fully preserved (fig. 19). At a distance up to 25 km big trees up to 25-30 cm in diameter were broken and felled by the force of the explosion (figs. 19, 20). Our main expedition camp (camp No. 1), separated from Bezymianny by a distance of 16 km, several deep valleys and barriers of lava flows and thought safe by us, proved to be within the zone of destruction. Fortunately at the time of explosion there was nobody there and in general, despite its strength, the eruption did not result in loss of any human lives.

Ashes of the directed explosion after falling on the ground still kept some amount of gases and were very mobile, « flowing ». They were rolling down from the elevated parts and filled all valleys of the rivers adjoining the volcano. Some sand streams were several meters thick.

At the moment of explosion the ashes were so hot that were scorching the bark of trees and bushes at a distance up to 27-29 km, and some trunks, belonging apparently to dry dead wood, were burning practically completely. The snow cover, which reaches here by the end of the winter 1-2 m, melted under the coat of incandescent ashes completely in the axial part of the explosion, and remained only partly in more remote points. Glowing material was deposited on an area of about 500 km^2 and the melting of snow was very violent. Torrential mud flows (lahars) were formed in the valley of Sukhaia Hapitsa and on the flanks of Kliuchevskaia and Zimina sopkas. These torrents rushed down carrying big stones and devastating everything they met on their way.

The largest mud flow began from the end of the agglomerate stream on Sukhaia Hapitsa; in the bed of the river mud accumulations, up to 20 m thick, remained at a distance of about 15 km. In the lower part of this mud flow glacial boulders are lying weighing up to hundreds of tons and having dozens of cubic meters in size. They have been brought here by the lahar (fig. 21). The mud here was hotter and its higher temperature in the upper section was preserved throughout the winter of 1956-1957.

Powerful mud flows descended also the flanks of Zimina sopka and the SE basement of Kliuchevskaia sopka, but here lahars were cold.

In the axial parts of the mud flows, dense and hardly passable forests were literally erased and the trunks carried away; sometimes only low, split stumps remained. Nearer to the borders of the flows trees and bushes were left standing and in some points impassable barricades were formed (figs. 22 a, 22 b).

Having reached the river Bolshaia Hapitsa in their movement to the East, the mud flows have turned along the valley to the North. In the vicinity of camp No 3 all lahars merged into one; an hour after the beginning of the eruption a mud flow destroyed here several dozens telegraph poles. Not only the poles but also trees were moved down like grass (fig. 23). The yourta, in which our camp No 3 was located, got completely flooded by mud (in other words the level of mud exceeded the level of the river at least by 15 m).

Further North the mud flow deviated from the bed of river Bolshaia (Big) Hapitsa. In the region of stream Chistaia (Clear) and lake Urukulon, at a distance of 80-85 km from the volcano, the lahar fell into the valley of the river Kamchatka. The lakes Katlynych and Bochkarevo were completely piled by debris transported by the mud flow. At the end of the lahar a sort of peculiar moraine was formed consisting of a chaotic mixture of dirt, trunks and branches of trees (figs. 24-25).

A ramified drainage system of channels and lakes safeguarded Kamchatka river from a catastrophic rise of water, but the masses of dirt contaminated the water so much that it became impotable in Ust-Kamchatsk for a whole week and could not even be used for technical purposes. Dirt also caused a mass mortality of fish in the river.

In the « Cheeks » of Kamchatka river (where the river cuts the Kumroch mountain range and all streams converge into one channel) the rise of water began during the night of March 30 to 31st; by the morning of March 31st the water had risen 11 cm, and by that evening - 33 cm. In the morning of April 2nd the rise reached its maximum (35 cm) and the normal level was attained only by the evening of April 5th. Judging by the speed of the current (0.42 m/sec) and the width of the river at that point (314 m), the additional volume of water, which fell into Kamchatka river is estimated at 1.5×10^7 m^3.

As a whole the scheme of eruption on March 30th is presented as follows: the gigantic explosion embraced not only the summit crater, but also the sqeezing out old dome on the SE flank of the volcano. The first explosion was directed to the SE at an angle of 30-40° to the horizon; in this direction a fan-like jet of incandescent ashes was bursting out with a tremendous force. The strength of this jet is proven by broken trees and peeled off trunks of bushes at a distance up to 25-30 km from the volcano. As a result of the explosion a large crater open to the East was formed. Its size was 1.5 × 2 km. Through a breach extremely powerful streams of glowing agglomerate and sand material rushed down into the valley of Sukhaia Hapitsa. Clouds of ashes over the crater and the agglomerate stream rose to a height over 40 km. NNE of the volcano an ashfall on an area of exceeding 400 km length took place. The tremendous mass of glowing material caused a quick melting of snow, which resulted in the formation of torrential lahars, which, in their turn, having passed about 90 km and destroying everything on their way, fell into the river Kamchatka.

At the moment of eruption on March 30th the summit crater of Bezymianny undoubtedly increased, but mainly from the SE side at the expense of ruining the dome; however, from the North and West the top of the volcano did not change its outlines (fig. 16). After the end of the eruption the walls of the crater collapsed and the crater greatly widened and the volcano got lower on its western side. Thus the picture here reminded the formation of calderas.

5) Stage of growth of the extrusive dome and end of eruption

Following the explosion of March 30th a sqeezing out of an extrusive (endogene) dome began in the new crater. The growth of the dome, as usually, was accompanied by explosions of a weak and moderate force. Very rarely stronger explosions took place, like, for instance, the rise of an ash-cloud for 8 km over the crater on June 21, 1956. Quite often incandescent avalanches were forming, which rolled down the flanks of the dome and sometimes through the breach in the crater got outside the limits of the volcano for 1-2 km.

By early July the formation of the dome was mostly completed. By this time it reached a height of about 300 m above the floor of the crater.

In August 1956 (fig. 26), the height of the dome was determined to be 320 m. The upper 140 m were the massive body of the dome, while the lower 180 m were hidden by brèches d'écroulement. The diameter of the dome was 340 m, its top had a diameter of 230 m and the basement of the brèches d'écroulement - 620 m. During this period often but very weak explosions were taking place in the dome exposing incandescent, glowing lava. Judging by a dull red glow the temperature of the lava did not exceed 700°. At the moments of explosions small incandescent avalanches were rolling down the slopes of the dome (fig. 27).

On August 27, 1956 the author with a group of employees made an ascent into the crater Bezymianny and, in order to collect samples of fresh lava, approached the base of the dome. In the SW part of the crater at the foot of the dome there was a crater-like bocca, from which dense puffs of gases were emanating. Unfortunately, the danger of a lengthy stay in the crater of an erupting volcano did not permit us to study the structure of the crater with more details (fig. 28).

Late in October we studied the volcano from an airplane (fig. 29). Analyses of pictures taken from the air had shown that in the place where we observed the SW bocca one more dome began to grow. Later measurements, after the end of the eruption, established that the second dome grew to a height of 260 m. This dome closely adjoined the first one; the common basement of the paired dome was 750 m wide and the summit was 320 m wide.

Late in the autumn of 1956 the eruption was completely over and by December of the same year the domes cooled so much that, with the exception of the top itself, were covered by snow entirely. During the following months the volcano displayed only an intense fumarolic activity (fig. 30).

«Valley of Ten Thousand Smokes of Kamchatka».

The most outstanding event in the eruption of Bezymianny volcano was the gigantic explosion of March 30, 1956 with all the phenomena which accompanied it and especially - the formation in the valley of Sukhaia Hapitsa of a big agglomerate stream with thousands of secondary fumaroles. This picture so vividly reminded the description of the Katmai flow, that we immediately christened this valley as « Valley of Ten Thousand Smokes of Kamchatka » (fig. 31).

We saw the agglomerate flow for the first time three weeks after the eruption from the neighbourhood of our camp No 1. Endless steam jets were merging in the height into one dense cloud, completely hiding the volcanoes Bezymianny and Zimina. Approaching the flow, we discovered that the fumaroles were associated mostly with the southern part of the valley and were grouped along a rather narrow line. Apparently, the fumarole smokes reflected the buried river channels. It should be said that previously this region had a dissected morainic topography, but now it presented a flat plain slightly inclined towards the East. All the ruggedness was buried under a cover of loose agglomerates many meters thick. At this time, in April, the flow was not yet dissected by river erosion and its surface was quite loose (fig. 32).

In details the agglomerate flow was investigated in summer of 1956. By this time its northern edge was cut by a deep bed of the river Sukhaia Hapitsa with plumb walls, the surface of the flow was also cut by a whole system of shallow beds of intermittent streams; the surface of the flow also bore evidences of a passage of channelless surface waters and was rather solidly cemented. Under a 2-3 meter solid crust the agglomerate remained loose.

In many points of the agglomerate flow and especially in its upper part, small explosion funnels were scattered. Explosions were taking place already when the flow stopped in its movement and, judging by all signs, were determined by a contact of incandescent material with underlying masses of ice or snow in places of their especially thick accumulations.

The agglomerate flow has rather complex outlines. At the moment of eruption the agglomerate, impregnated by gases, possessed a great fluidity and could not stay on steep flanks of the volcano. That is why there are practically no deposits of agglomerates on the flanks of the volcano and the flow begins seemingly not from the crater, but from the base of the volcano. In the narrow, long pan, which goes from the crater SE with a grade of 4-5°, the agglomerate is partly preserved but the thickness of the flow here is much less than in sections more removed from the crater and this part, contrary to the rest of the flow, cooled rapidly and in autumn of 1956 was partly covered with snow. Hills adjoining the volcano from the E divided the flow into three streams. Two of them (central and southern) merged at a distance of 5 km from the crater and here the flow is the widest - 4 km. The northern branch of the flow divided into two parts, one of which ended 15 km from the volcano near our camp No 4, and the second - followed the bed of Sukhaia Hapitsa and joined the main flow at a distance 10 km from the crater. Further down the valley the width of the flow gradually diminishes and the flow ends 18 km from the crater. At the end of the flow a characteristic swell is located, consisting of roughly rounded boulders of fresh lava. This swell reminds an end moraine line. Similar swells we observed also at the end of the route covered by incandescent avalanches of Sheveluch volcano (1).

The area occupied by the agglomerate flow is 55-60 km². The thickness of the flow in the marginal northern part amounts to 20-25 m, in the central part it is, undoubtedly, higher and comes, probably, to 50 m. If we take an average thickness of the flow as 30 m, the volume of the agglomerate flow will come to 1.8 km³. It is difficult to imagine the scale of incandescent avalanches which stormed here under the cover of the impenetrable ashfall.

By summer, fumarolic activity considerably weakened, however, thousands of steam jets still rose from the flow. On a clear, dry day they could hardly be discernible from a distance, but with a rise in the humidity of the air the apparent condensation of the vapours increased, creating the impression of fumarolic activity. The maximum temperature of fumarolic gases was 200°, predominant was the temperature of 100°.

The overwhelming majority of fumaroles was associated with the walls and beds of perennial and intermittent streams. The dependence of the location of secondary fumaroles on the filtration of water was quite obvious.

On clear and hot days mountain glaciers were melting more and water was rapidly increasing in the bed of Sukhaia Hapitsa. The banks consisting of hot agglomerate material were rapidly washed away, creeping down and collapsing into the water. Each such collapse caused a steam explosion — a peculiar « secondary eruption » (fig. 33) during which ashclouds were thrown up to a height of 200-300 m. Especially strong were explosion phenomena on those days when showers of rain were pouring in the mountains and torrents of water were rushing down not only along Sukhaia Hapitsa but also along the beds of intermittent streams and all over the surface of the agglomerate flow, cutting into it and making new channels. On the surface of the agglomerate flow hundreds and thousands of centres of secondary explosions were originating. Sometimes up went fountains of liquid mud (fig. 34), but more often clouds of ashes and tiny stones. Ashclouds rose to a height of 0.5 km and drifted 2-3 km to a side, sowing ashes. Quite often pisolites were dropping out of ashclouds. On such days our camp No 4 happened to be surrounded sometimes by many dozens of secondary explosion centres. The picture was really bewitching.

The water of Sukhaia Hapitsa was overfilled with loose material forming a thick but very mobile mud, in which big stones were swimming like trees quite easily. Especially strange was it to see how in oxbows after waterfalls the stones were swimming slowly and whirling in the streams of countercurrents. The mass of solid material was 90-95% and a pail of such mud gave by the morning only several centimeters of water. The tremendous amount of hot material collapsing into the water produced a considerable rise in the temperature of cold glacial waters; the temperature of the glacial river Sukhaia Hapitsa rose to 35-45°.

Throughout the winter of 1956-1957 the agglomerate flow remained warm on the surface and was not covered by snow. Fumarolic activity as compared with the summer of 1956 got by May, 1957 much weaker.

As will be shown later, reserves of heat in the agglomerate mass of the flow is still sufficiently great and there is reason to hope that fumarolic and explosions phenomena in the valley of Sukhaia Hapitsa will last for a long time.

Products of eruption

During the first period of eruption - during the phase of strong volcanic explosions - the volcano was ejecting a considerable amount of ashes. In all cases under a microscope fragments of glass were discovered in the ashes, hypersthene, plagioclase and small inclusions of magnetite. The glass and minerals had the appearance of sharp-edged little fragments, i. e. the ashes were representing hypersthene andesite crushed in a solid state. The ashes could be a product of crushing action in the old dome or maybe rocks of the strato volcano, or even mixed ashes. The average ashes had a chemical composition of a typical andesite. Table 1 gives under No 2 analysis of ash, collected after the ashfall of November 7, 1955 in camp No 2, 12 km from the volcano; for comparison No 1 gives analysis of lava from the strato volcano.

Lavas of the eruption of March 30th by their mineralogical composition differ from the ashes of the Vulcanian stage, - they are more acid hornblende andesites. In lavas of the agglomerate flow the microscope reveals in a hyalopilitic groundmass phenocrysts of plagioclase No 50-55, hornblende and, in smaller quantities, hypersthene. A mixture of magnetite is also encountered. Andesite of the dome differs from the lavas of the agglomerate flow only by the colour of the hornblende: in the agglomerate flow it is predominantly green, while in the dome - brown. In both cases crystals of hornblende are surrounded by an opacite rim.

Ashes which fell from the explosion cloud of March 30th in Kliuchi by their mineralogical and chemical composition were like to lavas of the dome or of the agglomerate flow.

Sand of the directed explosion, taken in the zone of destruction, is a mixture of hornblende and hypersthene andesite, as well as fragments of more basic rocks, apparently from the Kamen volcano - from the basement of Bezymianny. Fragments of all these rocks are easily distinguishable in larger fractions of sand.

It should be noted that the fraction of smaller clastic material of the agglomerate flow considerably differs by its chemical composition from the blocks of fresh lava. Study of fragments under the microscope, as well as inspection of stones 1-3 cm in size, permitted to establish that the finer clastic part of the agglomerate flow consists of a mixture of the most varied rocks, including basalts of Kamen volcano.

Table 1 gives chemical analyses of rocks connected with the eruption of Bezymiannaia sopka. Analyses have been done in the chemical-analytical laboratory of the Kamchatka Volcanalogical station of USSR Academy of Sciences, by I. I. Tovarova.

Chemical composition of lavas

	1	2	3	4	5	6	7
SiO_2	57.69	57.82	59.79	59.48	59.94	58.19	59.94
TiO_2	0.92	0.96	0.89	0.65	0.88	0.96	0.84
Al_2O_3	17.69	16.85	17.39	17.59	17.57	17.28	17.18
Fe_2O_3	2.37	3.70	3.79	4.08	3.17	3.76	3.53
FeO	4.21	3.34	3.15	2.93	3.22	2.86	3.32
MnO	0.12	0.16	0.12	0.14	0.14	0.19	0.14
MgO	4.35	4.41	2.82	2.49	2.91	3.73	2.80
CaO	7.42	7.31	7.16	6.82	6.97	7.34	6.89
Na_2O	3.59	3.09	3.67	3.66	3.80	3.83	3.46
K_2O	1.20	1.32	1.27	1.29	1.32	1.14	1.23
H_2O —	0.08	0.32	0.25	0.10	0.20	0.11	0.16
H_2O +	0.20	0.54	0.29	0.77	0.14	0.49	0.09
Total	99.84	99.82	100.59	100.00	100.26	99.88	99.58

1 - Hypersthene andesite of stratovolcano.
2 - Ashes of the first phase of the eruption. Near the base of the volcano.
3 - Ashes of the eruption on March 30, 1956 (in Kliuchi).
4 - Hornblende - andesite of the first portion of the agglomerate flow.
5 - Hornblende - andesite. Lava of the agglomerate flow.
6 - Fine fraction of the agglomerate flow.
7 - Hornblende-andesite of the new dome.

Gases. Some idea of the composition of eruptive gases is given by the analyses of water extractions from fresh ashes. In the anion part of the extractions sulphate-ion prevails (up to 0.5 % to the weight of the rock), then follows chlorine (up to 0.2 %), always present are carbon dioxide, fluorine and boron.

During heavy ashfalls a smell of sulphurous gas was usually felt; analyses of the air in Kliuchi at the moment of the ashfall on March 30th established the presence of 2.2 mg/1 CO_2 (0.11 %), 0.295 mg/1 SO_2 (0.01 %) and 0.106 mg/1

HCl (0.006 %). This shows that even at a distance of 45 km from the volcano at the moment of the ashfall considerable quantities of volcanic gases were contained in the air. There is no doubt that in the eruptive cloud at the crater concentration of gases was much higher. It is not surprising that the ashes absorbed a certain amount of gases and, possibly, of volatile sublimates.

In water extractions from the ashes and in the air hydrogen sulphide was not discovered, but during the ascent to the crater and in the flights over the volcano a sharp and definite smell of hydrogen sulphide was felt quite distinctly. This smell is pervading everywhere on the agglomerate flow as well.

Secondary fumaroles of the agglomerate flow are steam jets with a mixture of air and acid gases. So, one of the fumaroles, which deposited sulphur, in September, 1956 had the following composition: (under a temperature of about 100°): 74.3 % of water vapour, 9.9 % of carbon dioxide, 0.3 % of hydrogen sulphide and 15.5 % of air; in addition about 0.01 % of methane was present (analyst L. A. BASHARINA). The air is poor in oxygen, the ratio of oxygen to nitrogen was 1/48 instead of 1/4 in the atmospheric air. Apparently, intense oxydizing processes are proceeding in the depth of the agglomerate flow, which can partly be connected with the carbonization of plants, buried under the mass of agglomerates. Sometimes a mixture of sulphur dioxide was determined in the fumaroles. In condensates of fumarolic gas also the presence of certain amounts of hydrogen chloride was observed.

Gas, collected after the eruption (in April, 1957) in the crater of Bezymianny at the base of the new dome, consisted of (with the exception of water vapours): 27.2 % of acid gases and 72.2 % of air. The air had a normal ratio of oxygen and nitrogen.

Sublimates. Around fumaroles of the agglomerate flow and the dome sublimates were deposited in abundance consisting of a mixture of chlorides and sulphates; some fumaroles were also depositing sulphur.

Earthquakes associated with the eruption

The eruption of Bezymianny was preceded and accompanied by numerous earthquakes. Their registration took place in Kliuchi, 45 km from the volcano with the help of Kirnos seismographs with uniform acceleration 500 in the interval from 0.2 to 10 sec. and Kharin seismographs with a « peak » characteristic (10.000 acceleration on a period of 0.2 sec.). In both cases the registration was galvanometric on photographic paper.

The total number of shocks in Kliuchy during nine months (beginning with October, 1955 up to June, 1956) was 33150; in other words, every 12 minutes there was an earthquake. This vast material is not completely studied yet and we will speak only about the main features of these earthquakes.

The number of earthquakes and their energy are presented in the form of a graph on fig. 35. The lower curve shows the total number of earthquakes for each ten days by months, the upper curve logarithm of seismic energy in ergs for the same periods of time. As the graph shows, the number of earthquakes and their energy do not coincide. The number of earthquakes in the process of eruption was sharply changing, while their energy remained approximately on the same level during a lengthy period of time.

The character of seismicity during the first, preeruptive phase of the eruption was described at the beginning of the preceding chapter. Without repeating the data presented there, we will just point out that during the preeruptive period the number of earthquakes and their energy were rapidly growing and the growth of the energy was surpassing the growth of the number of shocks and by the end of this period the energy of the earthquakes reached its constant value of about 10^{20} ergs for ten days, while the number of earthquakes did not reach the maximum yet and was by the end of the period 200-220 shock per day.

At the beginning of the eruptive stage of the eruption the number of earthquakes rapidly reached maximum values of 350-450 per day (up to 3750 shock per ten days). The absolute maximum of earthquakes for a day took place on November 10 (470 shocks) (fig. 36).

The sharp rise in the number of earthquakes during this period of eruption occurred mainly at the expense of very feeble shocks, which were virtually not reflected in the energy balance. Corresponding estimates show that from the district of Bezymianny volcano our seismic station could confidently register shocks the energy of which was reaching values of about 10^{13} ergs, which corresponds to explosions of about 10^{16}-10^{17} ergs force, i. e. rather moderate volcanic explosions. There is no doubt that a sharp increase in the number of earthquakes was determined by a growth in the intensity of explosions. By the end of the stage of powerful ash eruptions, along with the weakening of explosions began just as sharp a drop in the number of shocks. On November 24th still 303 shocks were registered, while next day their number dropped to 100 for a day. In future such high figures for the number of earthquakes, as in the middle of November, were not observed any more.

Despite the fact that in December, 1955 and January, 1956 the number of earthquakes considerably decreased and the apparent manifestations of volcanic activity considerably diminished, the energy of earthquakes was preserved on the same level and we expected a further development of the eruption.

In February, 1956 a certain increase in the number of shocks was noticeable, which, apparently, was connected with shifts of the old dome and explosions, producing hot avalanches.

Beginning with the end of February a steady drop in the energy of earthquakes was observed. It seemed that the eruption had exhausted its strength and was coming to an end. But just at that time, on the decline of seismic energy, the gigantic culmination explosion of March 30th took place, which was reflected on the curve of the energy as a sharp

« peak ». Following this peak seismic energy resumed its steady drop and by the end of June, 1956 the energy of earthquakes dropped to values of 10^{13} ergs for one day. Later lower values of energy we did not calculate.

Despite a general drop in the seismic energy during the phase of growth of the dome, the number of shocks in April and May, 1956 was obviously growing and during some days in April reached practically 300 per day. This increase in the number of shocks was, apparently, connected with the processes of growth of the new dome. By the end of June the number of earthquakes dropped to 1 a day. By this time the dome was mostly formed completely.

An extremely weak seismic activity continued, gradually dying down, until the end of 1956.

All earthquakes, associated with the eruption of Bezymianny, sharply differ from usual local tectonic and volcano-tectonic earthquakes by their large period (2.5-3 seconds, instead of 0.2 sec) and a peculiar maximum phase after the arrival of S wave. All larger earthquakes with the minutest details repeated each other and had the same source and cause; they had a greater depth (about 50 km) and originated, apparently, within the magmatic reservoir or in the lower part of the volcanic channel. A peculiar form of recording of these earthquakes could have been explained, maybe, by the propagation of elastic waves through the liquid magmatic reservoir.

The number of earthquakes and partly their energy were in direct association with the process of eruption, but, as stated above, the curve of the number of earthquakes and of their energy did not coincide. The reason of this noncoincidence lies in the fact that in computing the number of shocks all oscillations were taken into consideration, including even the very feeble ones, associated with volcanic explosions and other surface phenomena. The energy characteristic depended mainly upon the stronger shocks, all of which, without exception, had a greater depth and were a consequence of deeper volcanic processes, which determined the *general course* of the eruption.

Some phenomena, associated with the explosion of March 30

The explosion of March 30th was followed by a strong earthquake, the records of which sharply differ from the records of thousands of preceding shocks. All preceding shocks were damped in 5-10 minutes, while this earthquake was recorded, gradually damping during 50 minutes. Judging by the first arrival, the earthquake had a hypocentre at a depth of about 50 km and should have been over rapidly; its lengthy duration, is due, apparently, to a recording of a surface explosion superimposed upon the record of the first earthquake.

During two days preceding the explosion 2-4 weak earthquakes were taking place every hour. During the 15 hours which followed the explosion the number of shocks even dropped, and then, beginning with 10 a. m. of March 31st a practically uninterrupted recording began, reminding spasmodic volcanic tremor with $T = 1$ sec. and $A = 1\,\mu$. Beginning with early April 1st the record became uninterrupted, the period increased up to 1.2 sec. and the amplitude up to 1.5-1.8 μ. Since 8 a. m. the vibration got weaker and since 4 p. m. the vibrations acquired a discontinuous character and began to disappear. As a whole the record reminded a spasmodic volcanic tremor; it could also have been a conjoint recording of incessant weak earthquakes, which reflected the establishment of the depth equilibrium disturbed by the catastrophic explosion.

It is interesting to point out that the explosion of March 30th was not heard neither near by nor at a distance; some observers mentioned only a feeble muffled rumble. At the same time all meteorological stations within a radius of at least 1000 km registered on their barograms a distinct blast * (fig. 37). The rotation speed of the cylinder on usual station barographs is small, which makes the precision in determining

---

*) Microbarographs recorded the blast on all the world. The blast air wave went round the world one and a half time.

the time on barograms not very accurate. Consequently it was not possible to determine the velocity of propagation of the blast in the neighbourhood of the volcano with a sufficient accuracy. In the first approximation this velocity for different directions proved to be not uniform. In the western direction it was somewhat less than the sound velocity; in the eastern - somewhat higher (for a distance of 120 km). Such a difference is undoubtedly determined by the eastward direction of the explosion.

Comparison of the blast amplitude on different stations stresses the influence of the directed explosion even more definitely. So, for instance, in Kliuchi and Kozyrevsk, at the same distance from the volcano (45 km) the amplitude was 23.5 and 11.0 millibars correspondingly; for Ust-Kamchatsk and Esso (120 km from the volcano) it was 7.5 and 5.0 millibars (it should be remembered that these points are located in two opposite directions from the volcano). The amplitude of the blast is inversely proportional to the distance from the volcano; If the distance to the points is determined where the amplitude of the wave is 1 millibar, it will then correspond to 900-1000 km to the East, and only 500-600 km to the West. Actual data coincide with the expected.

A side effect of the explosion was the formation of seiches in the mouth of the river Kamchatka. During the explosion the tide was at its maximum and conditions of a closed water reservoir were created in the mouth of Kamchatka river. The blast resulted in the formation of standing waves - seiches. Their double amplitude came to 10-12 cm, and the period to 18.5 min. (fig. 38). At 10.30 a. m. on March 31st a full ebb was in action and conditions of a closed basin were discontinued and seiches disappeared.

It should also be noted that during the ashfall on March 30th a sharp increase in air humidity was observed in Kliuchi (fig. 39), though the ashes were falling dry. At the moment of eruption the humidity was about 50 %; with the beginning of the ashfall it began to rise and at 7 p. m. reached 63 %, after which a rapid increase in humidity up to 93 % occurred and beginning with 7.20 and up to 9 p. m. a drop to 67 % took place. It should be remembered that by 9 p. m. the ashfall was coming to an end and patches of clear sky began to show. In such a way during the ashfall in addition to volcanic gases there was also an increase in the atmosphere of water vapours, which was, it seems, directly connected with the eruption.

Let us try to estimate the energy of the blast on March 30th; we have several ways for this. *)

1. Having calculated the energy of the earthquake, connected with the explosion and considering that during the explosion about 0.1 % of the total energy is discharged as seismic energy, it is possible to evaluate the force of the explosion. The energy of the earthquake was determined by surface waves with the help of a nomographic chart, suggested by N. V. Shebalin (3). The average value of the energy according to data from five seismic stations of the Far East (Petropavlovsk, Magadan, Yuzhno-Sakhalinsk, Kurilsk and Vladivostok) amounts to $E = 10^{20}$ ergs. From this the total energy of the blast is 10^{23} ergs.

2. The energy of the blast can be evaluated according to the air wave of the blast. For the energy of an air wave Taylor offers a formula (6):

$$E = \frac{2\pi RH \operatorname{Sin} \varphi}{\rho_0 V} \int Po^2 \, dt \qquad [1]$$

Where R - radius of the earth, H - height of a uniform layer of the atmosphere (13000 m), V - sound velocity, ρ_0 - density of the air at the ground, φ - distance from the source of explosion in degrees.

Replacing in formula [1] numerical values of the symbols we get:

$$E = 1.25.10^{14} \sin \varphi \int Po^2 \, dt \qquad [2]$$

---

*) Preliminary data (2,9) have been somewhat changed and made more precise in this report as a result of later computations.

Replacing in [2] $P = A \sin \omega t$ we have:

$$E = 1.25.10^{20} \sin \varphi \Sigma \frac{A^2 t}{2} \qquad [3]$$

Here A - amplitude of the wave in meteorological millibars, t - in seconds and E - in ergs.

For Kliuchi the energy is estimated to be 6.4×10^{22} ergs; by data of other meteorological stations the energy of the air wave was somewhat less. The average value for the energy of the air wave according to records of eight meteorological stations, situated at a distance from 45 (Kliuchi, Kozyrevsk) up to 760 km (Kamenskoe in the mouth of the river Penzhina), is 3×10^{22} ergs. This twenty times exceeds the energy of the air wave from the explosion of the largest hydrogen bomb (1.4×10^{21} ergs, according to YAMAMOTO (7)). But this does not mean that the energy of the explosion of Bezymianny 20 times exceeds the force of the explosion of a hydrogen bomb (4×10^{23} ergs). In a hydrogen bomb not more than 0.3 % of the entire energy goes over into the air wave. During volcanic eruptions into an air wave is, apparently, transferred about 10 % of the entire energy, i. e. the total energy of the explosion at Bezymianny, according to these data, is approximately 3×10^{23} ergs.

The determination of the energy of an air wave is a rather simple problem and a comparison of energy of various volcanic explosions would be convenient by the energy of the air waves formed. With this purpose all volcanological stations should be equipped with microbarographs, in order to be able to register large volcanic explosions of any volcano on the Earth and weaker explosions in the vicinity of the station.

3. The energy of the explosion could be determined by the mass and velocity of ejected material, according to the formula:

$$E = \frac{mV^2}{2} \qquad [4]$$

The mass of ejected material can be roughly appraized by the volume of the crater formed. At an average diameter of 1000 m and depth of crater of 600 m, its volume is determined as 0.5 cubic kilometers and the mass of ejected material at a density of 2.4 as 1.2×10^9 t.

The original velocity of the explosion can be determined by the distance to which the material has been ejected, considering the angle of ejection. A maximum distance of a body ejected obliquely is achieved at an angle of ejection of 45°, which approximates the explosion angle at Bezymianny. By the explosion of March 30th eruptive material has been transferred to a distance up to 25 km and at the same distance trees have been broken by the force of the explosion. Let us accept the range of « shot » as 25 km. Then according to formula

$$Vo = \sqrt{rg} \qquad [5]$$

the original velocity will be 500 m/sec. Actually this velocity was, apparently, even higher, because we did not consider air resistance. The original velocity approached, probably, 600 m/sec. i. e. it exceeded the sound velocity practically twice. It becomes clear why for near by meteorological stations, located in the direction of the blast the speed of the blast exceeded sound velocity.

The maximum velocity of the blast, apparently, should not be used for the determination of the energy, because the average velocity was somewhat lower. A mass drop of eruptive material was observed at a distance up to 13 km from the volcano, which corresponds to the initial velocity of 360 m/sec. This velocity we are going to use.

Putting in the established values of mass and velocity into formula [4] we will find kinetic energy of the blast amounting to 8×10^{23} ergs.

As we see, the blast energy determined by three independent methods, despite all the approximation in computations, generally speaking coincides, keeping the value of $n \times 10^{23}$ ergs. The average value of the explosion of March 30th amounts to 4×10^{23} ergs.

It is possible also to evaluate the original pressure at the moment of explosion. MATUZAWA thinks (4) that at the moment of explosion the Bernoulli law remains actually valid for pressure and velocity of the ejected material, i. e.

$$P = \frac{\rho Vo^2}{2} \qquad [6]$$

where P - is pressure, ρ - density of the material, Vo - initial velocity. From this for a velocity of 500 m/sec a pressure of 3000 atm. is obtained, and for a velocity of 360 m/sec - 1500 atm.

Judging by the volume (1.8 km^3) and mass 3.3×10^9 t) of the agglomerate flow, the thermal capacity of the rocks (1.1×10^7 ergs) and the temperature of the explosion (about 600°), the heat energy of the eruption is determined at 2.2×10^{25} ergs. In such a way the energy of the explosion is only about 2 % of the total heat energy of the eruption. This result is most remarkable from the point of view of the role of heat and energy of gases in the process of eruption. As we see the energy share of gases is more than modest. From this point of view the old premises that « gas is the active agent and the magma is a vehicle » (5) should be critically reconsidered. Apparently, the main active agent of the eruption is the heat energy of the magma, and gas only serves to transform this energy into an explosive one and the efficiency of a volcano as a heat engine is very low.

Conclusion

Summarizing some numerical values for the eruption of Bezymianny we get the following results: total energy of the eruption - 2.2×10^{25} ergs, explosion energy on March 30th - 4×10^{23} ergs, volume of material ejected by the explosion - about 1.0 km^3, its weight 2.4×10^9 t. Volume of agglomerate flow - about 1.8 km^3, its weight - 4.3×10^9 t. Initial velocity of the explosion up to 500-600 m/sec. Initial pressure up to 3000 atm. All these figures characterize the eruption of Bezymianny as really gigantic.

The Bezymianny eruption, by its force, stands in one row with the eruptions of Krakatau, Katmai and Mt. Pelée. By its character, it is very close to Katmai eruption.

A comparison of the eruptions of Bezymianny and Katmai permits, it seem to us, to establish some errors in conclusions regarding the formation of the Katmai agglomerate flow and the eruption of Katmai in general. Owing to lack of space and time I am not going to discuss this in detail here; in the near future I hope to make a special report devoted to this subject.

BIBLIOGRAPHY

1. - Gorshkov, G. S. and Bylinkina, A. A. - *The observations of the Sheveluch volcano eruption in 1948-1950.* Bull. of the Volcanol. Station, No 20, Publ. Acad. Sci, USSR, Moscow, 1954. (In Russian).
2. - Gorshkov, G. S. - *The eruption of Bezymianny volcano (preliminary report).* Bull. of the Volcanol. Station, No 26, Publ. Acad. Sci. USSR, Moscow, 1956. (In Russian).
3. - Shebalin, N. V. - *Earthquake energy, intensity and focal depth.* Bull. Acad. Sci USSR, Geophys. ser., No 4, 1955. (In Russian).
4. - Minakami, T. - *On explosive activities of andesitic volcanoes and their forerunning phenomena.* Bull. Volc., Sér. II, tome X, Napoli, 1950.
5. - Perret, F. A. - *The eruption of Mt. Pelée 1929-1932.* Carnegie Inst. Washington, Publ. 458, 1935.
6. - Whipple - *The great Siberian meteor and the waves, seismic and aerial which it produced.* Quart. Journ. R. Meteorol. Soc., v. 56, No 236, 1930.
7. - Yamamoto, R. - *The microbarographic oscillations produced by the explosions of hydrogen bombs.* Weather, v. 10, No 10, 1955.
8. - Bull, G. A. and James, D. G. - *Dust in the stratosphere over western Britain on April 3 and 4, 1956.* Meteorol. Mag. G. B., v. 85, No 1012, 1956.
9. - Gorshkov, G. S. - *Les éruptions géantes du volcan Bezymianny.* Abstracts of the Reports at the XI General Assembly I.U.G.G. The Intern. Ass. Volc. Moscow, 1957.

PLATES

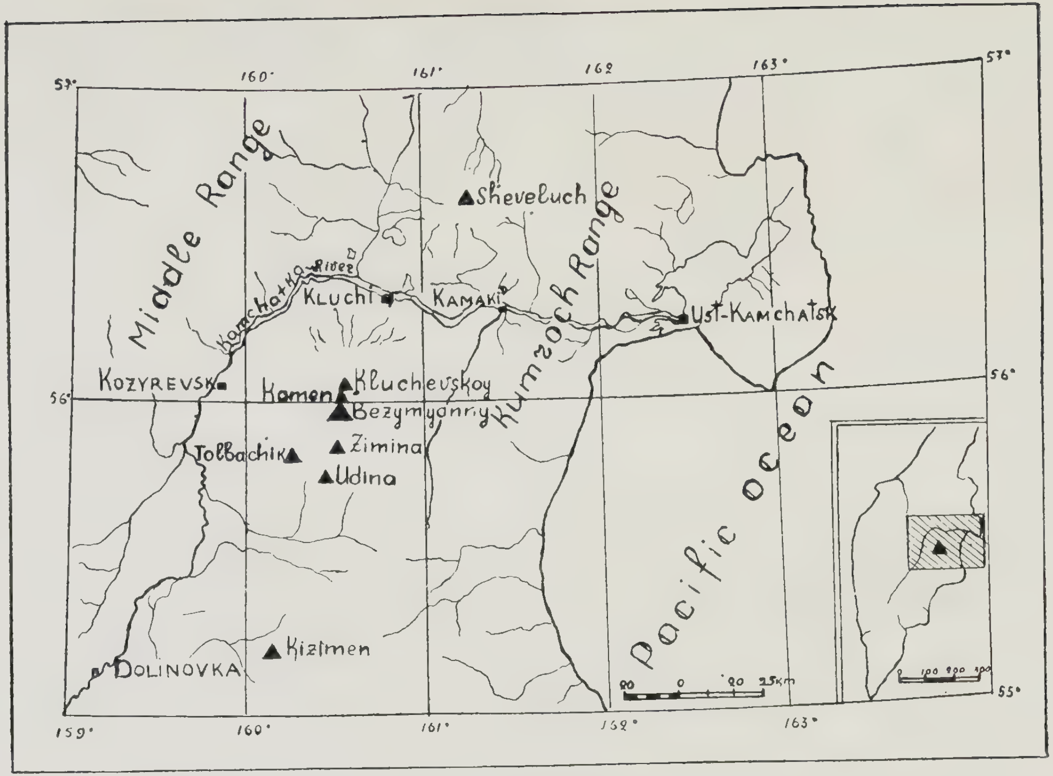


FIG. 1 - Areal map of the location of Bezymianny volcano among other volcanoes of Northern Kamchatka. ▲ —volcanoes, ■ —settlements.

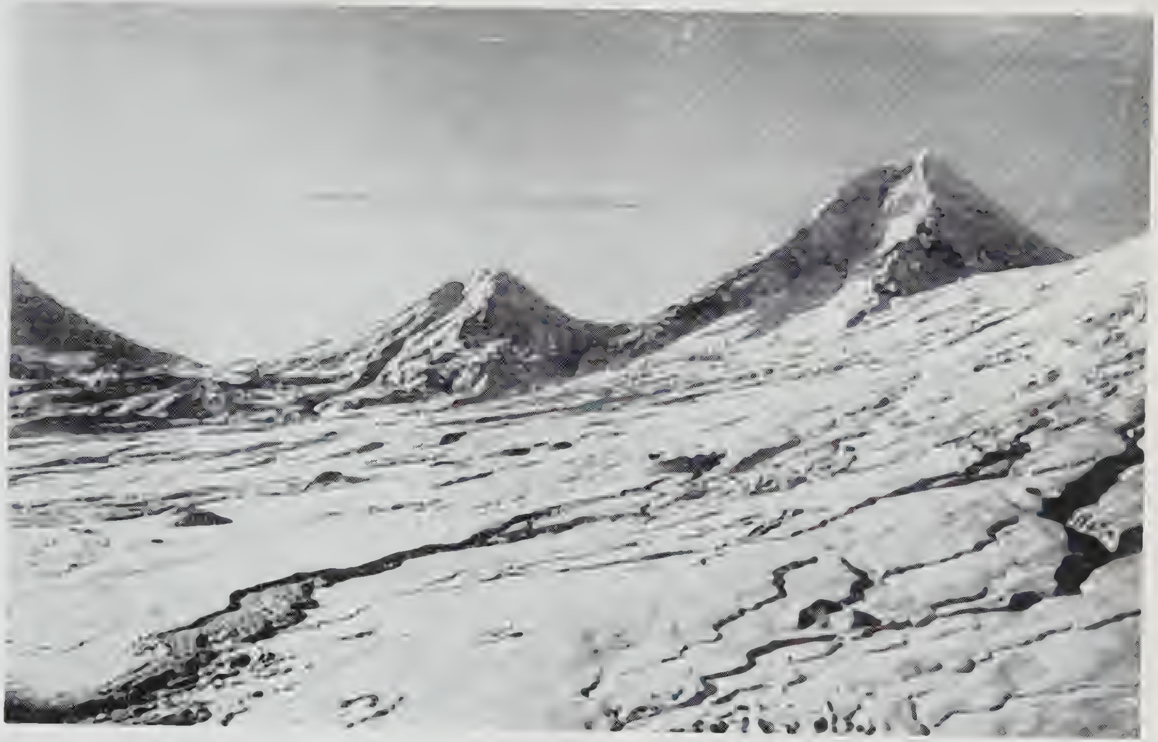


Fig. 2 Bezymianny volcano before the eruption (left), on the right Kamen volcano January, [illegible]

(Photograph by the author).

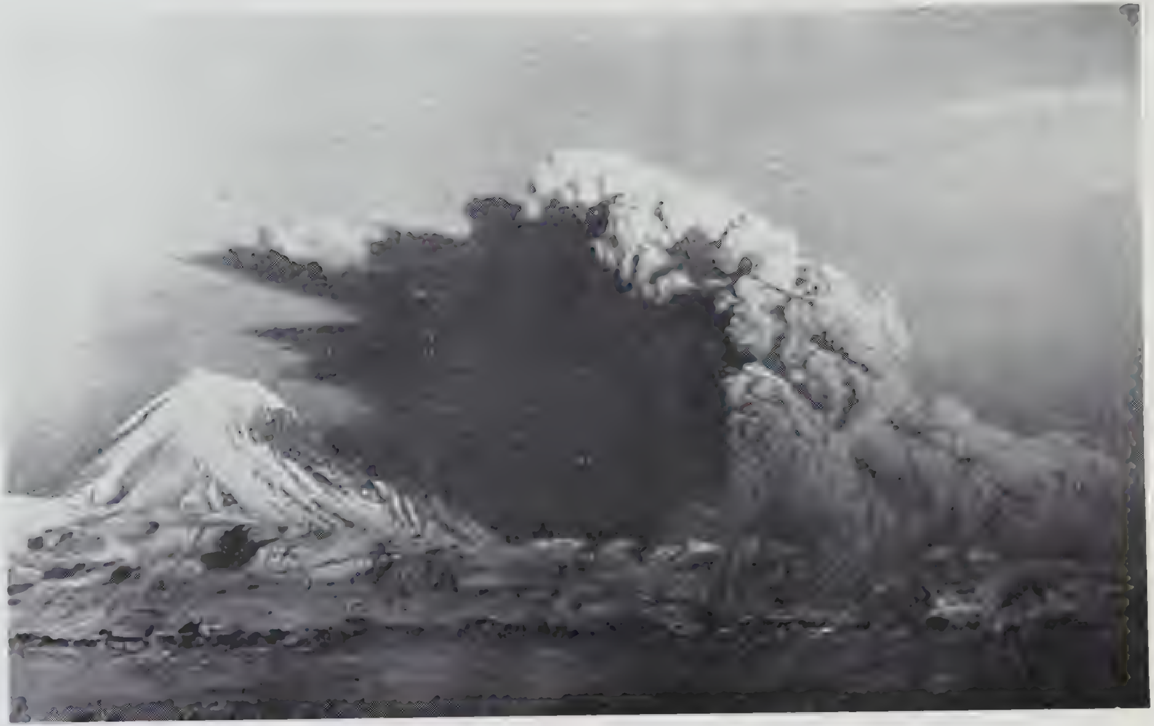


FIG. 3 - Bezymianny eruption on October 28, 1955. View from Kozyrevsk.
(Photograph by V. A. SHAMSHIN).

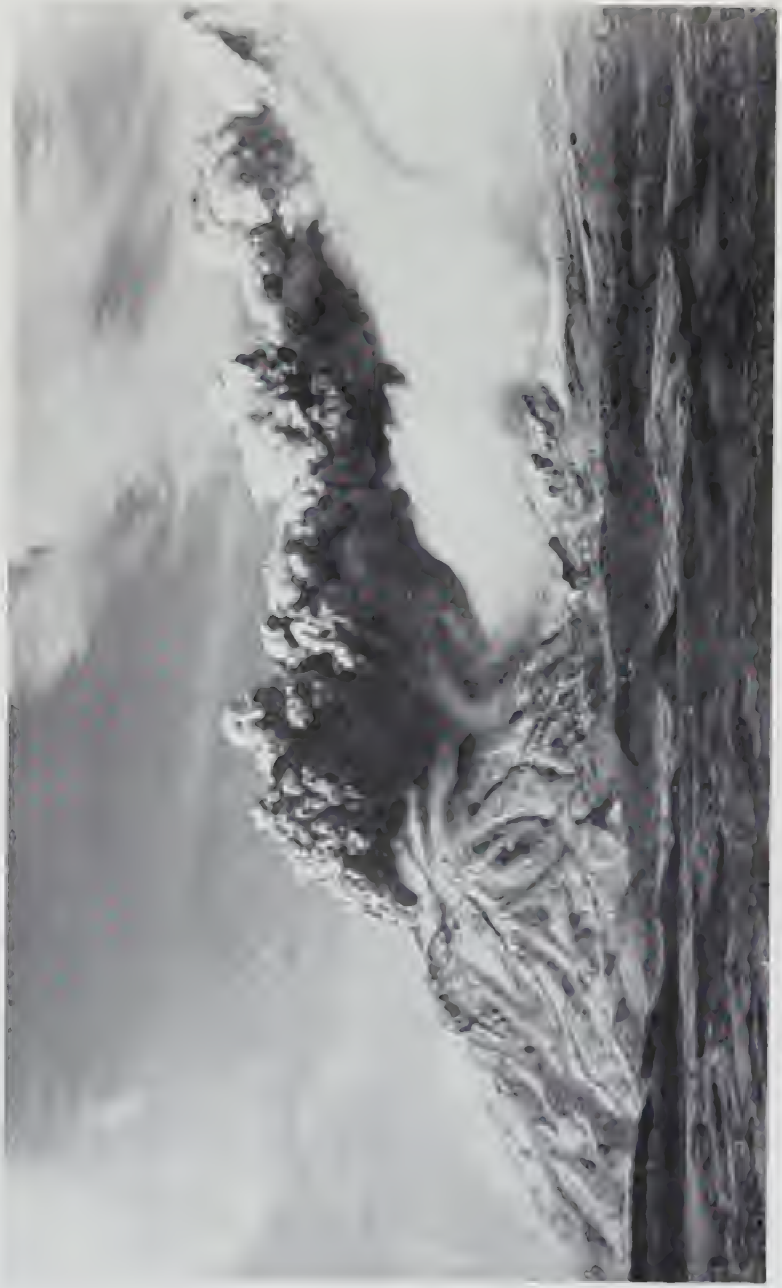


Fig. 1. Bezymianny eruption on October 30, 1955. View from camp No 1
(Photograph by the author)

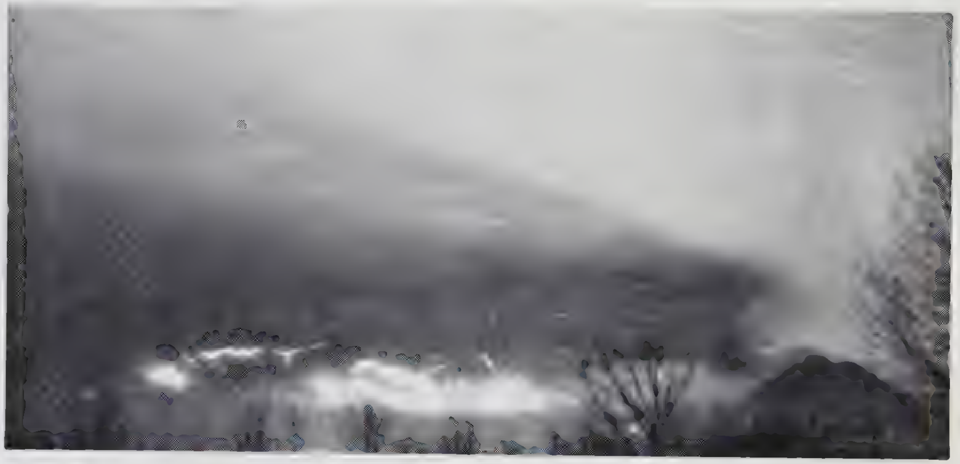


Fig. 6 - Lightnings in the eruptive cloud on November 13, 1955 night view from Kliuchi.
(Photograph by the author)

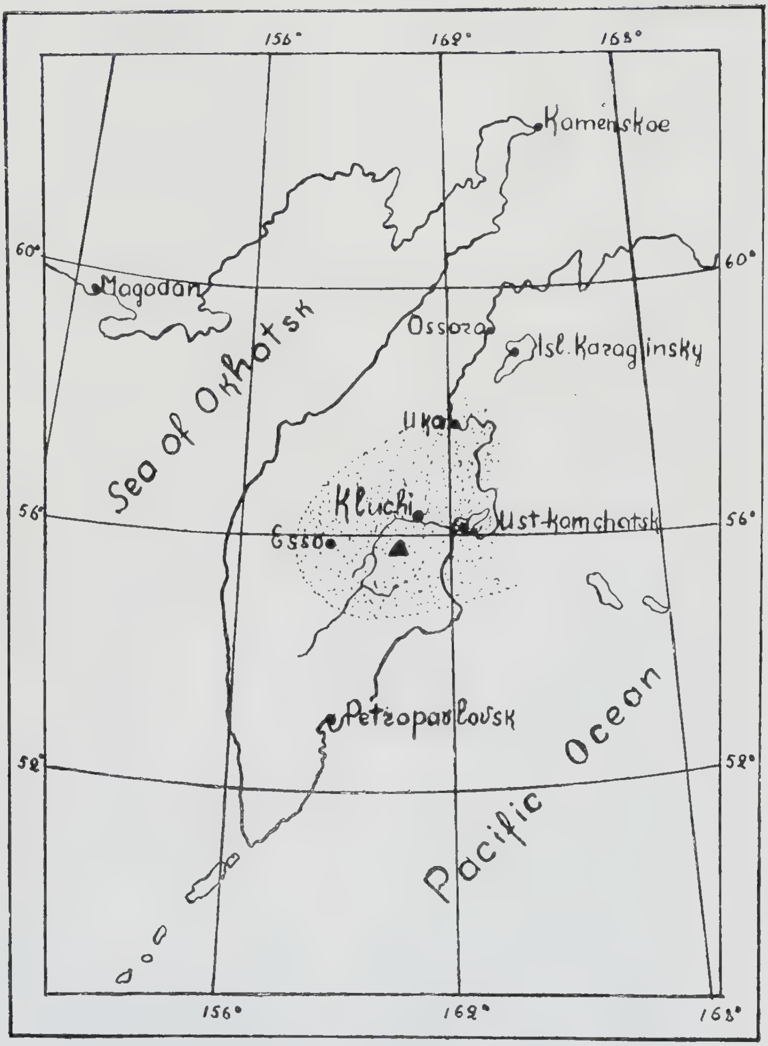


Fig. 7 - Distribution of ashfalls in November, 1955.

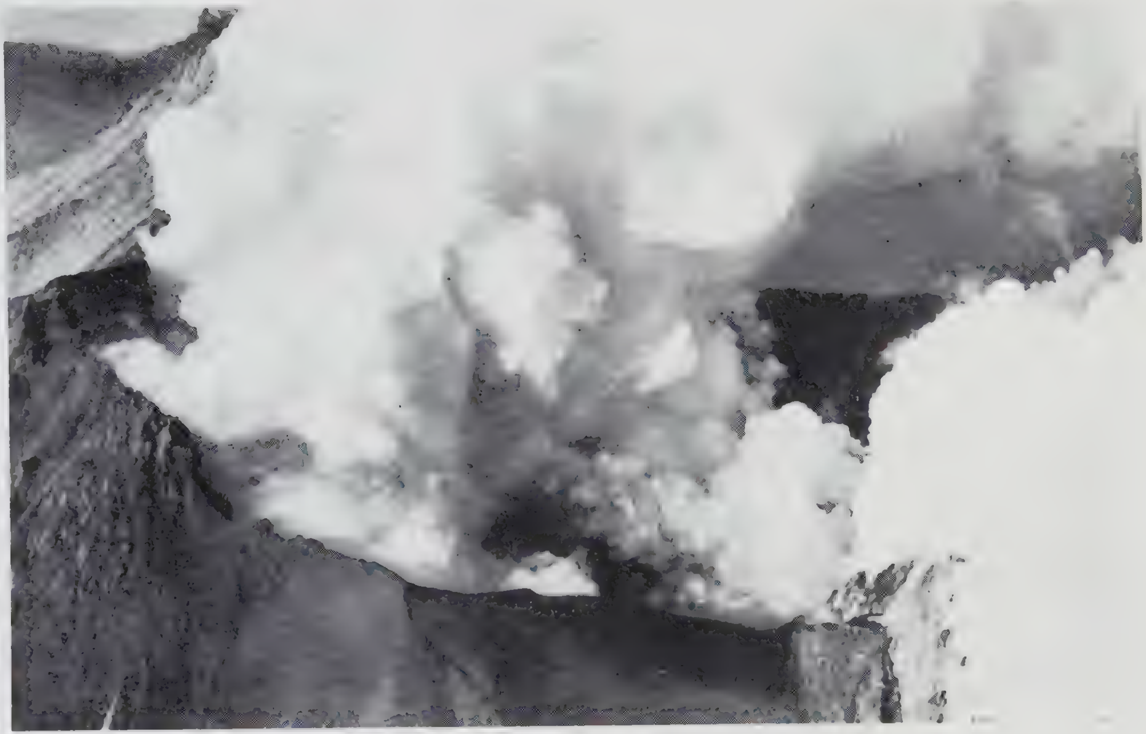


Fig. 8 · Bezymianny crater on January 25, 1956.
(Airphoto by the author).

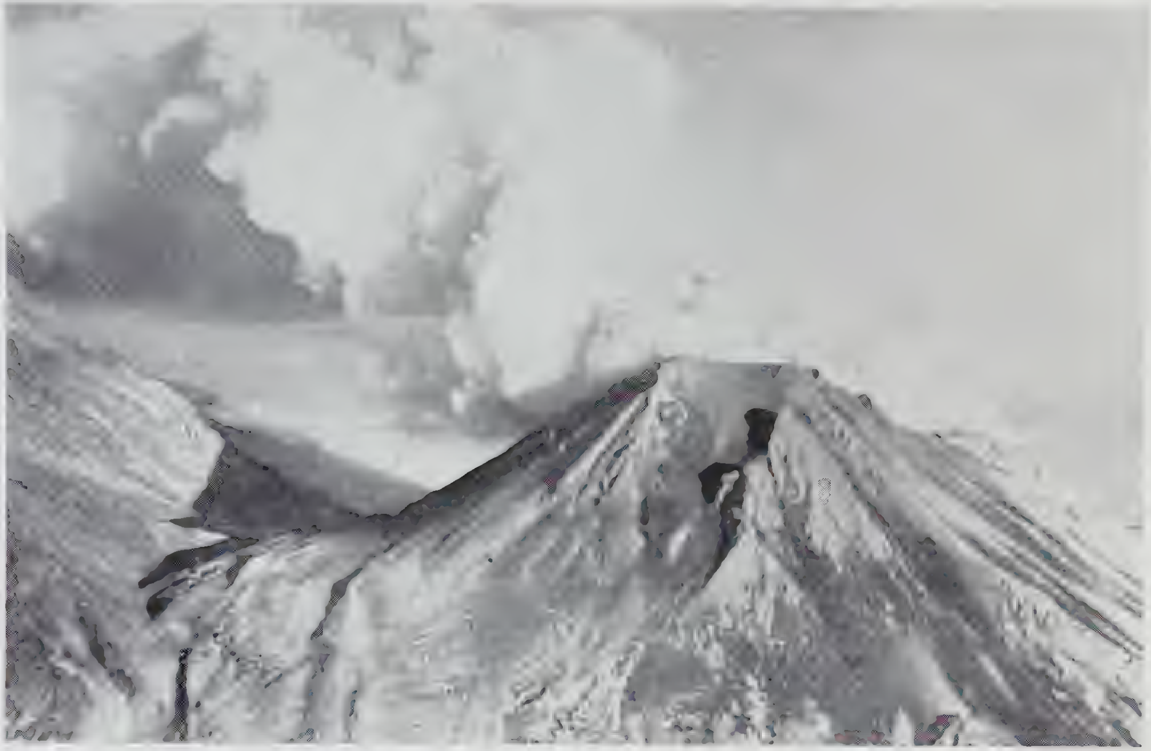


FIG. 9 - Fumarolic activity of Bezymianny volcano on January 25, 1956.
(Airphotograph by the author).

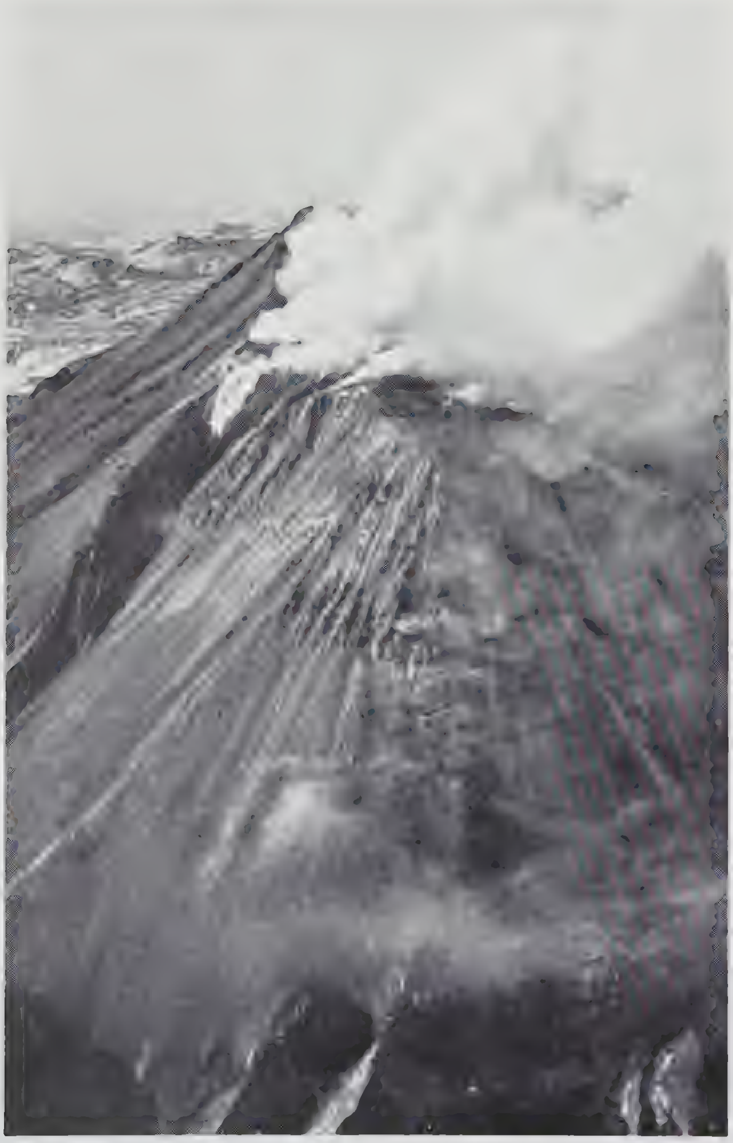


Fig. 10 - Old dome on the SE flank of Bezymianny.
(Airphotograph by the author).

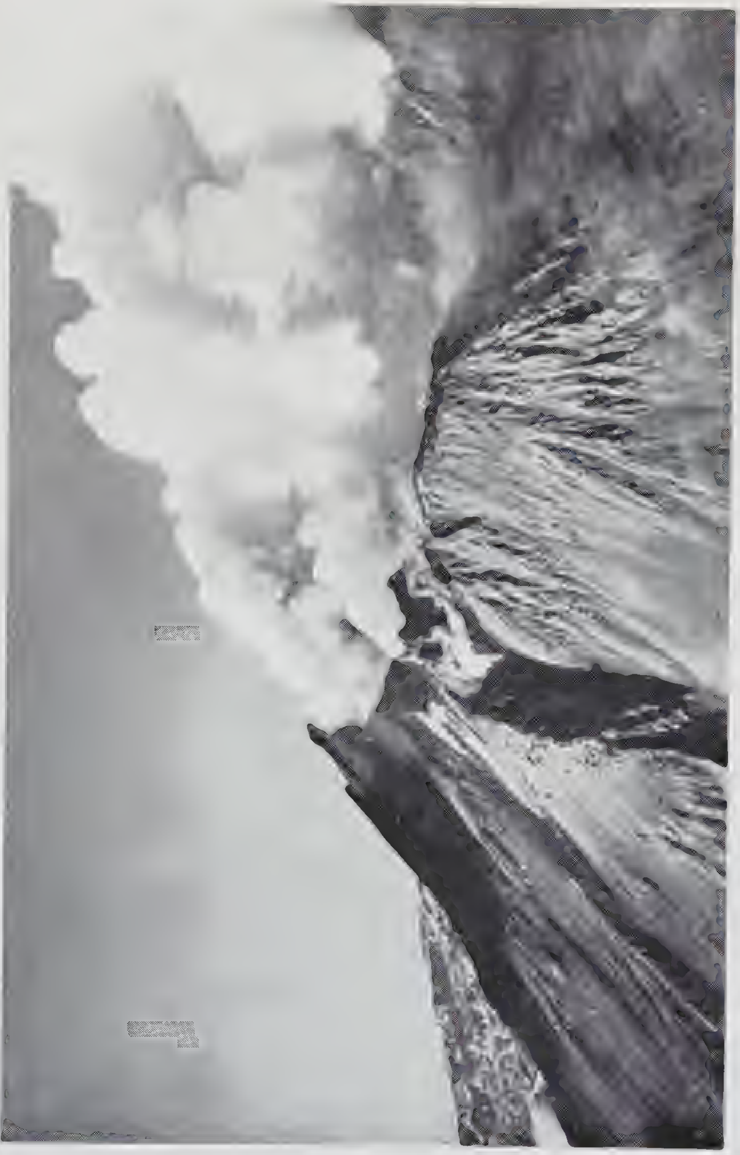


FIG. 11 - Southern flank of Bezymianny in January, 1956.
(Airphotograph by the author).

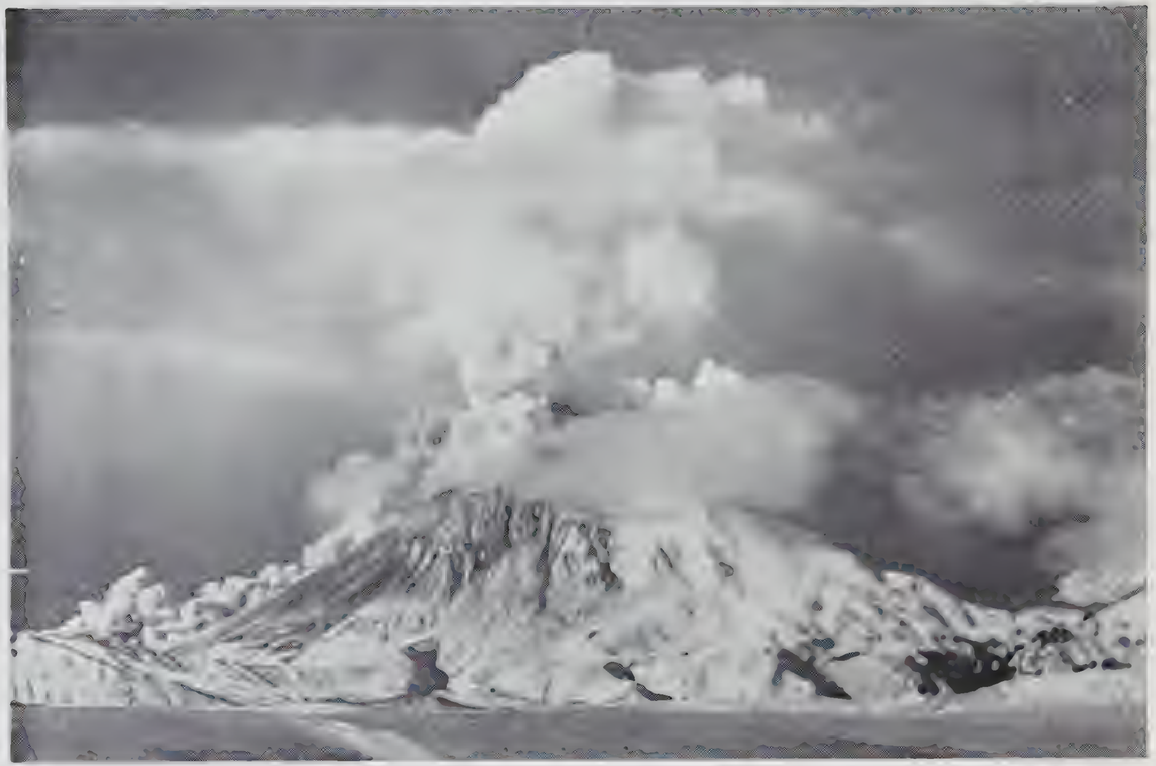


Fig. 12 – Incandescent avalanche on the southern flank of Bezymianny on February 9. 1956.
(Photograph by N. K. Klassov).

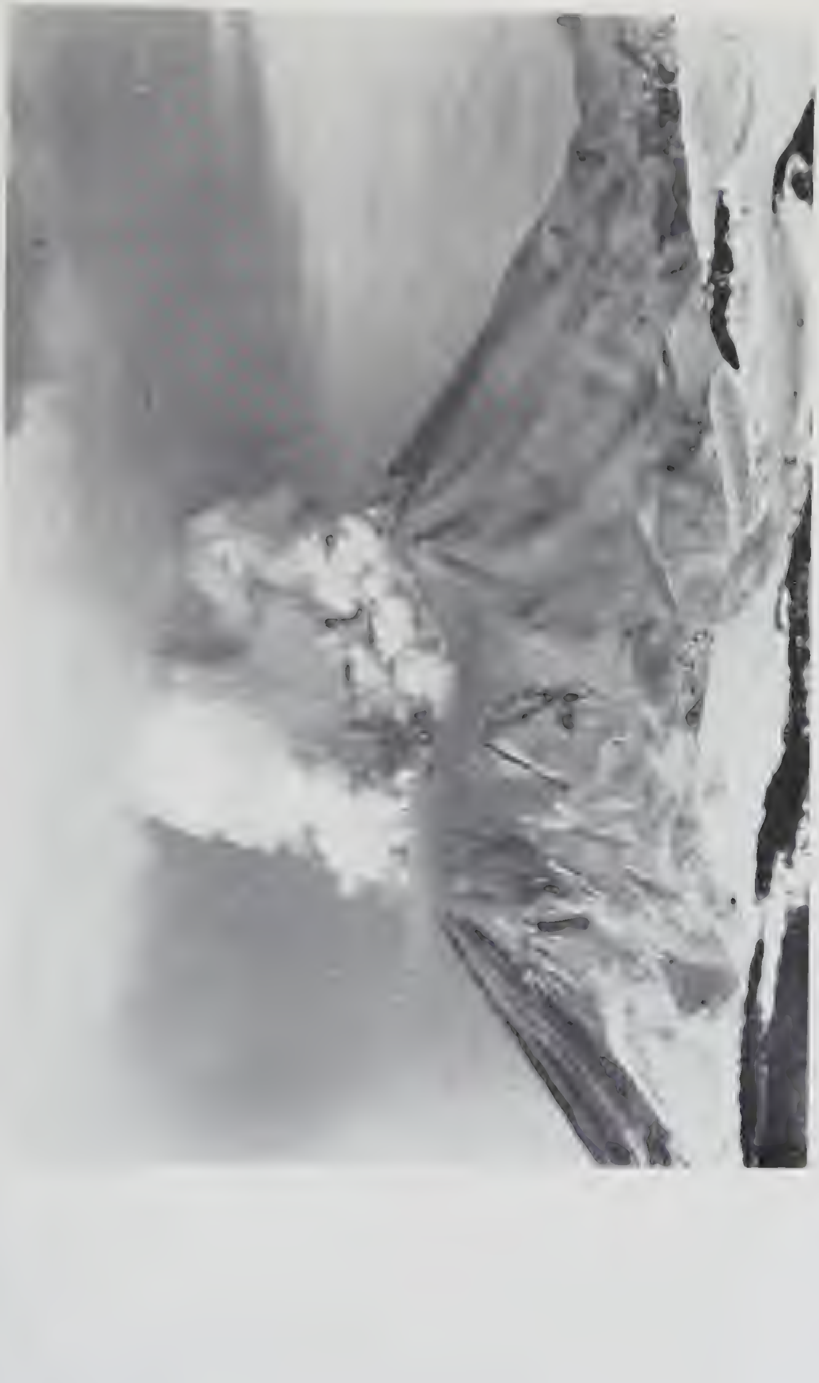


Fig. 14 - Bezymiannaia sopka in February 1956. View from camp No 1.
(Photograph by N. I. Klassov).

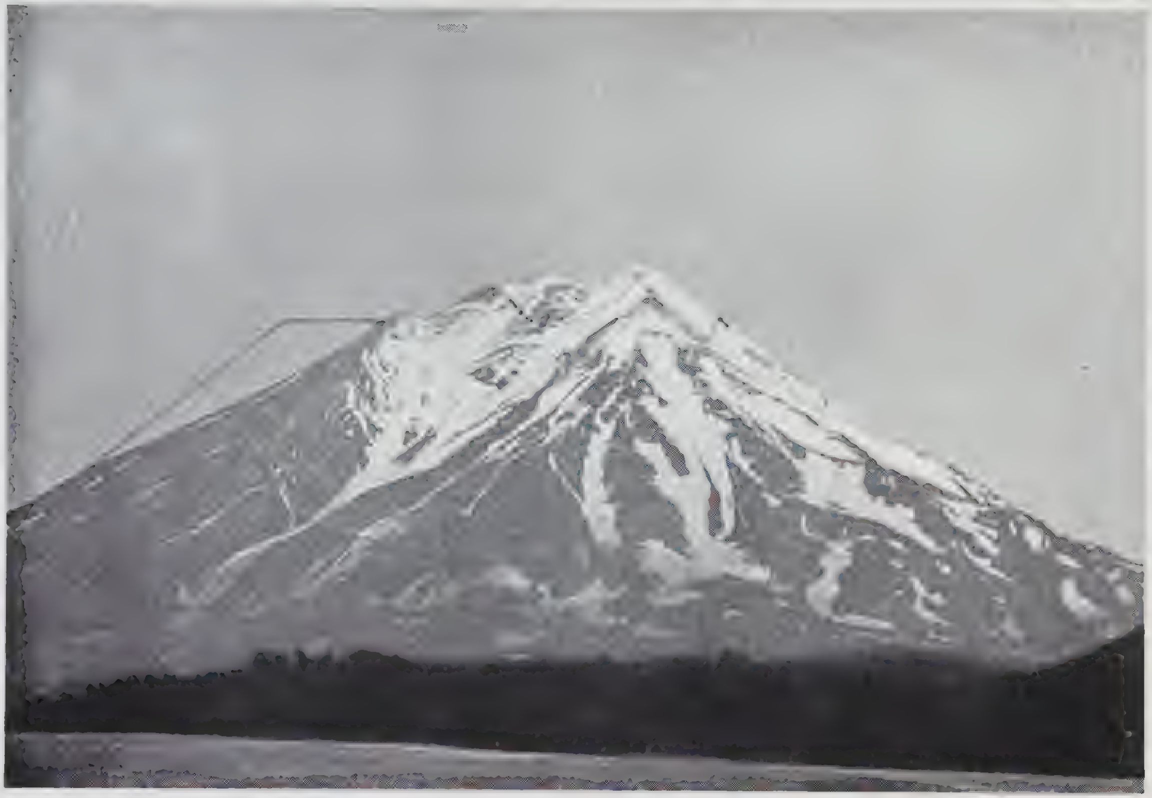


Fig. 14 Bezymiannaia sopka before the eruption (July, 1949); thin line shows outlines of the volcano in February, 1956, dots - crater on October 30, 1955.

(Photograph by the author

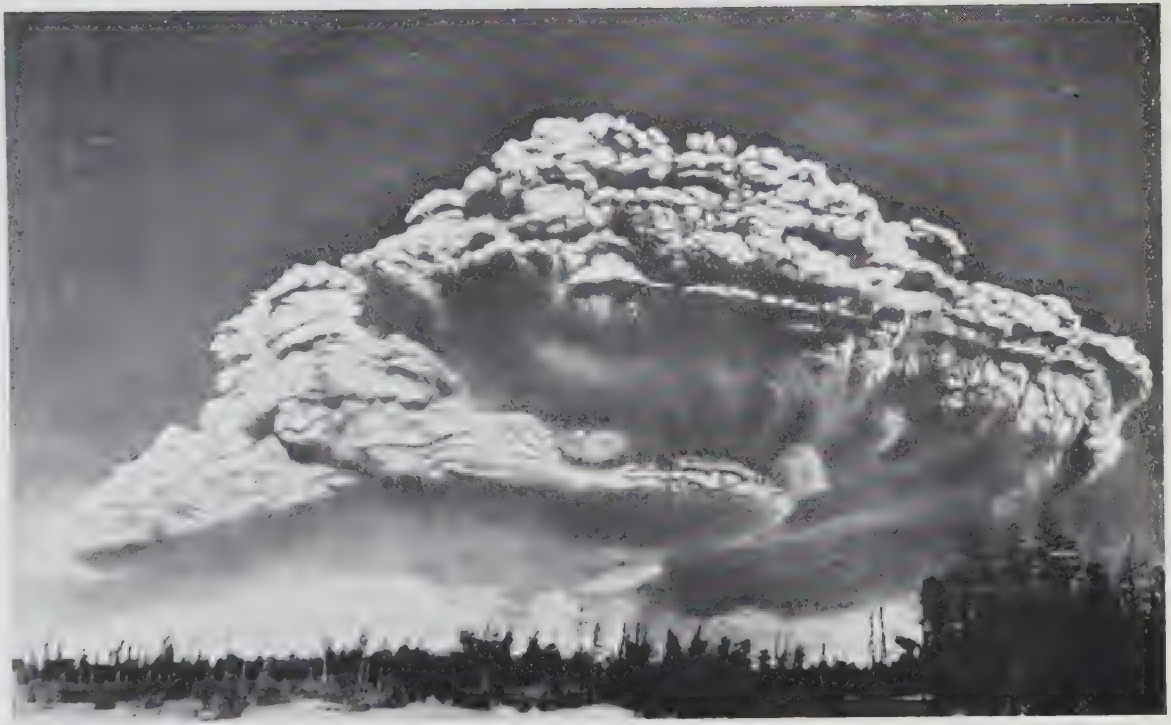


FIG. 15 - Panorama of the eruptive cloud on March 30, 1956; in the bottom on the left in a cap of clouds - volcanoes of Kliuchevskaia group. View from the vicinity of Kozyrevsk.

(Photograph by I. V. Erov).

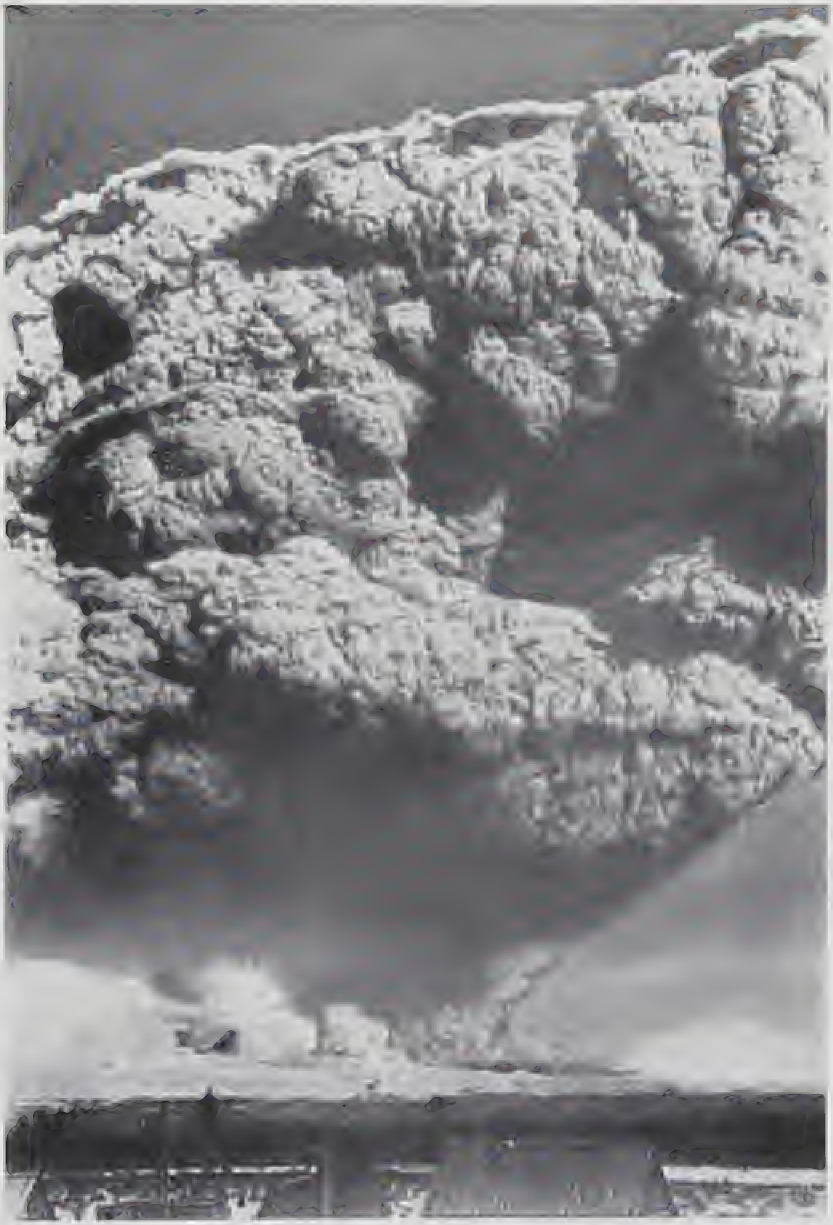


Fig. 16 - Eruption of Bezymianny on March 30, 1956. View from Kozyrevsk (Photograph by V. A. Shamshin).

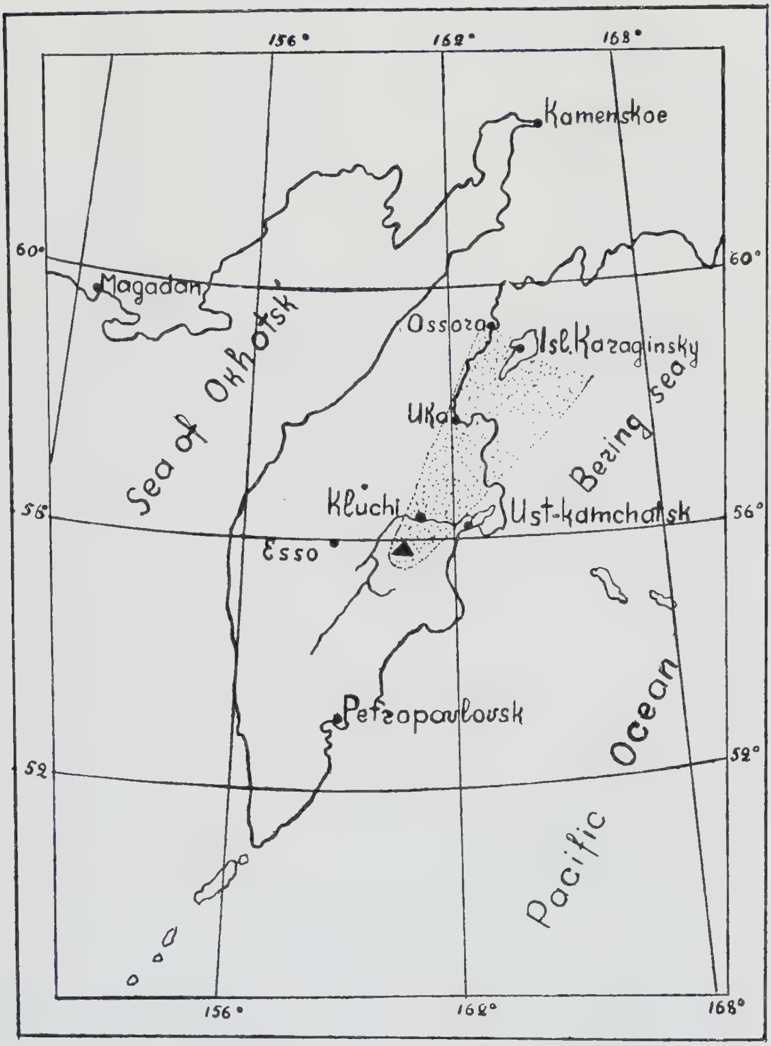


FIG. 17 - Distribution of the ashfall on March 30, 1956.

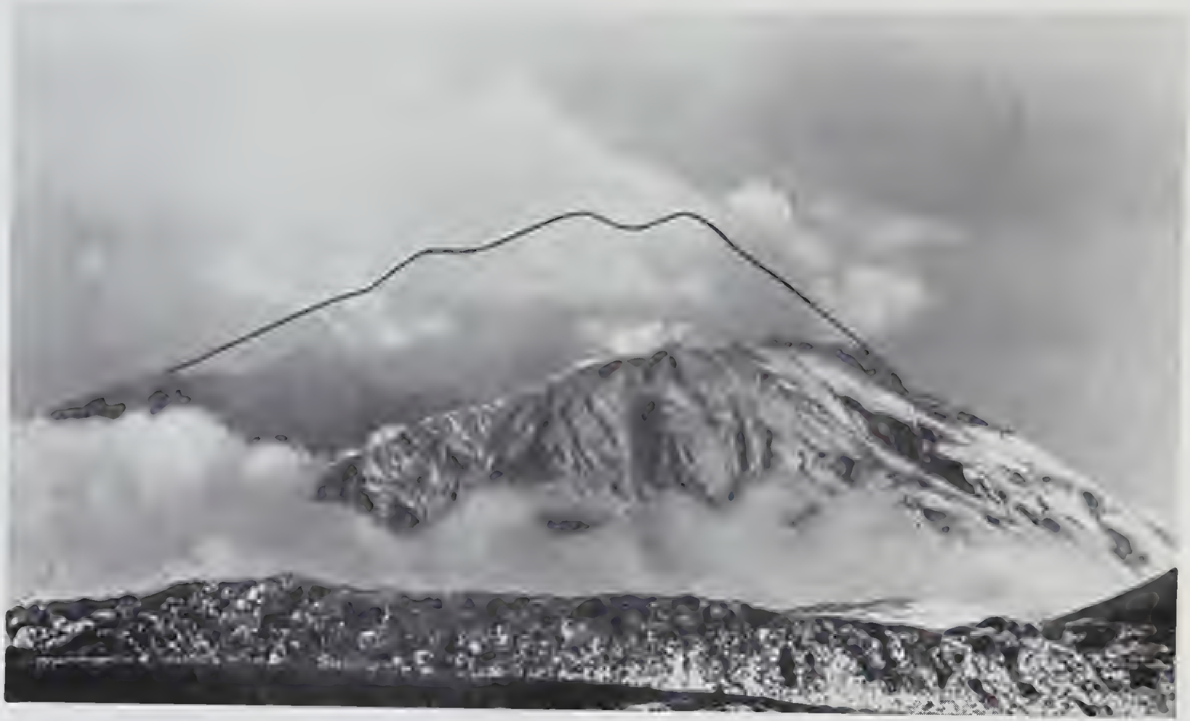


Fig 18 - Bezymianny volcano after the explosion of March 30, 1956 (photograph taken in April, 1956) - black line shows outlines of the volcano before the eruption See fig. 14 taken from the same spot before the eruption.

(Photograph by the author)

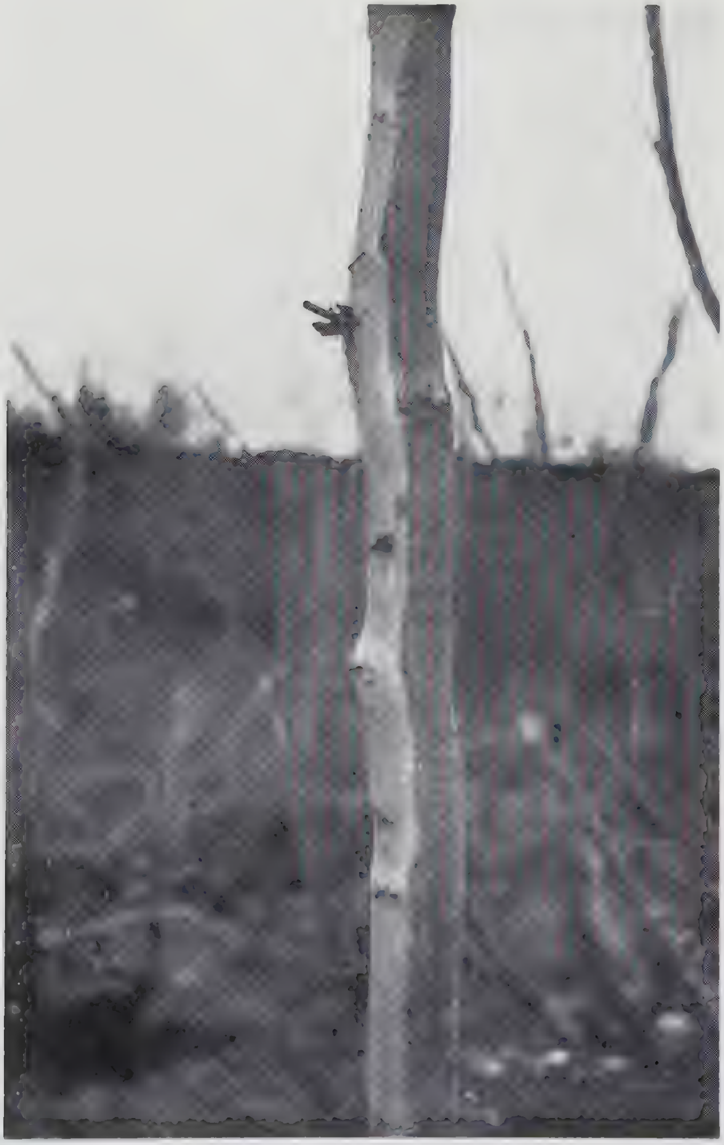


Fig. 19 - Trunk of an alder, stripped by a hot sand jet at a distance of 16 km from the volcano (camp No 1).

(Photograph by the author).

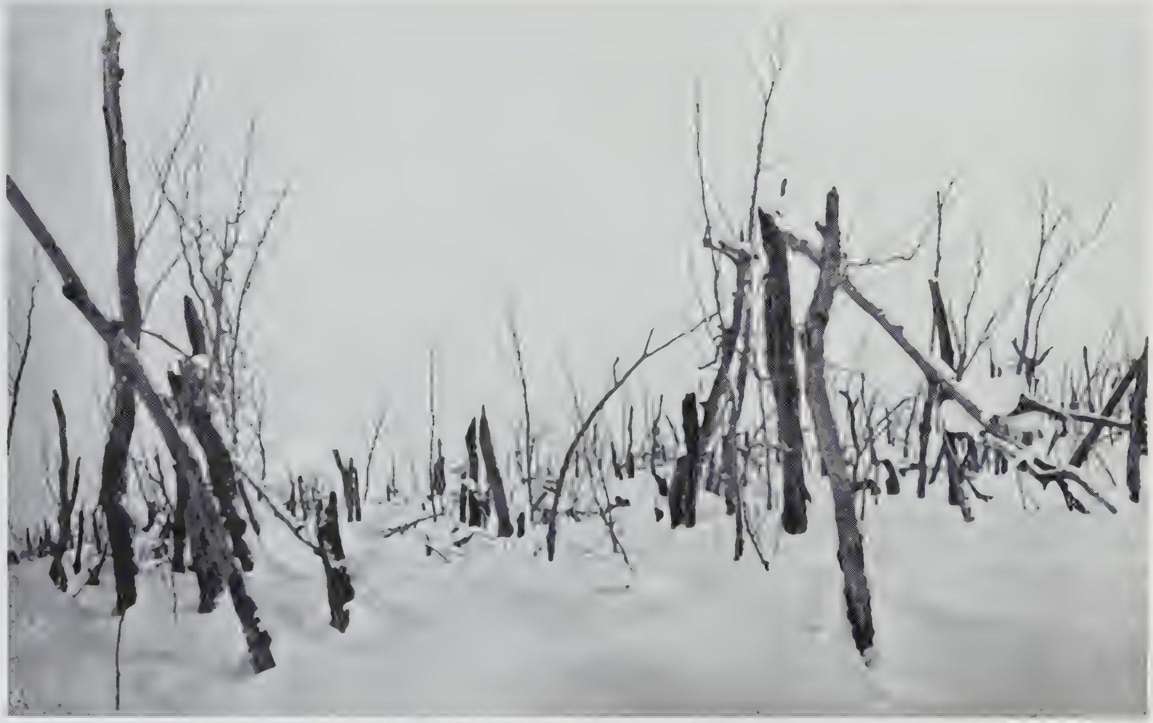


Fig. 20 - Forest felled by the explosion at a distance of 25 km from the volcano.

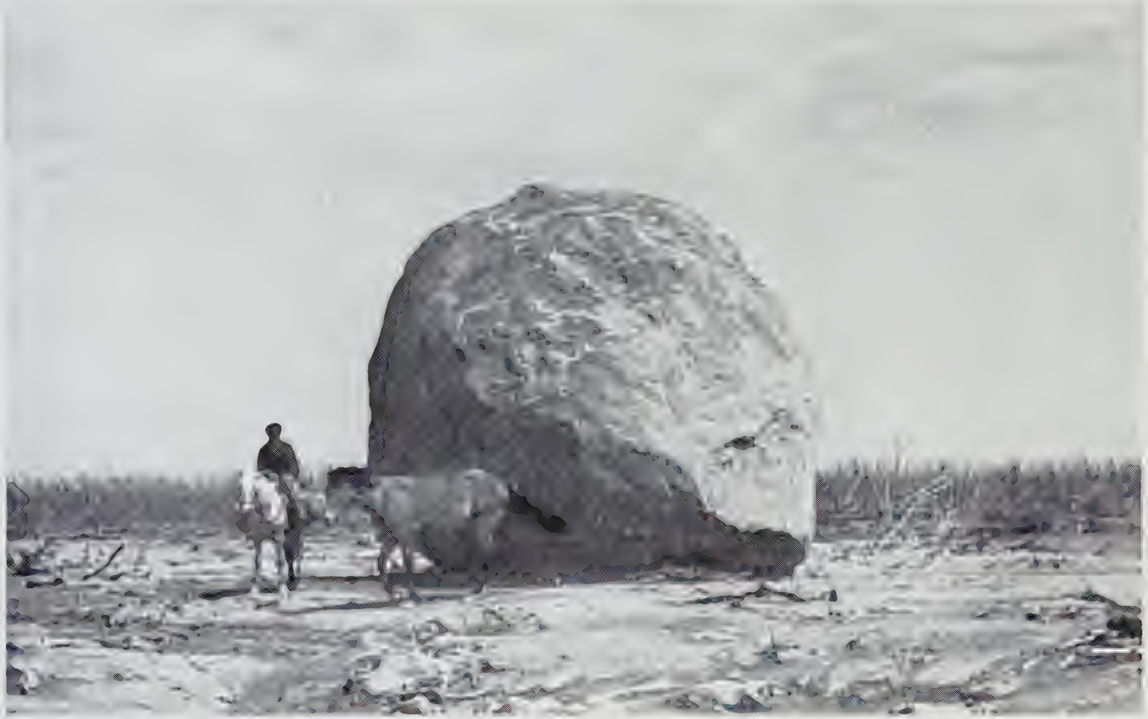


Fig. 21 - Glacial boulder, brought by a lahar
(Photograph by N. [illegible])

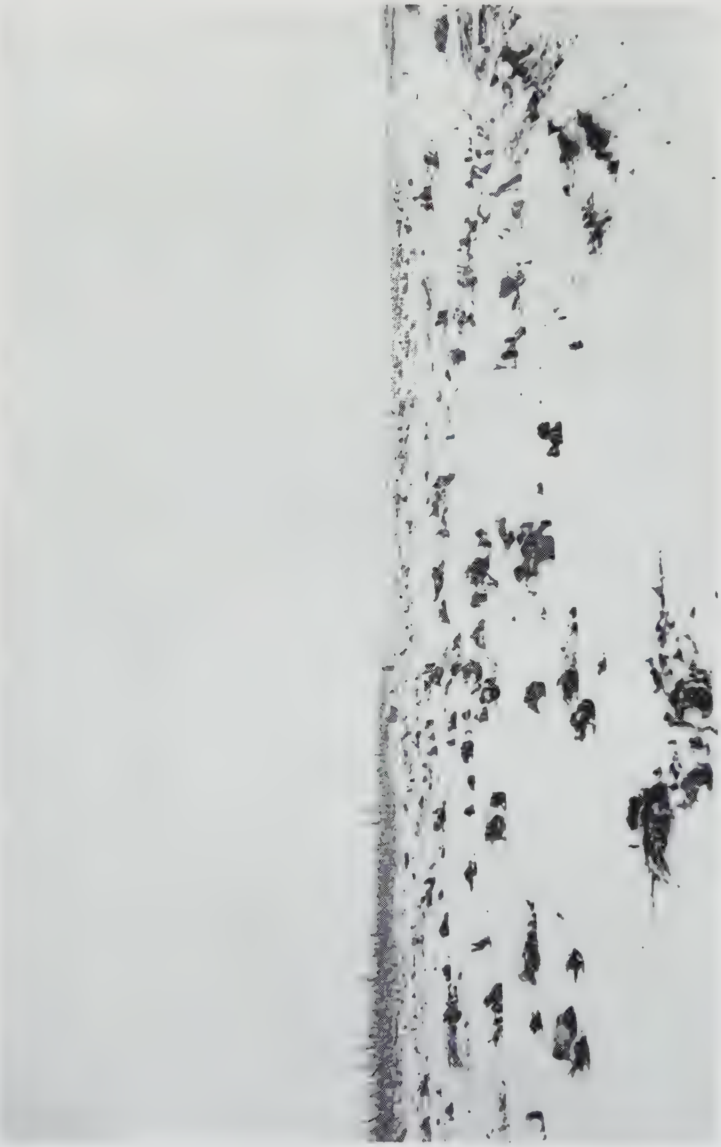


Fig. 22 *a* - Traces of a lahar: in the axial part - all trees destroyed, April, 1956.
(Photograph by the author).

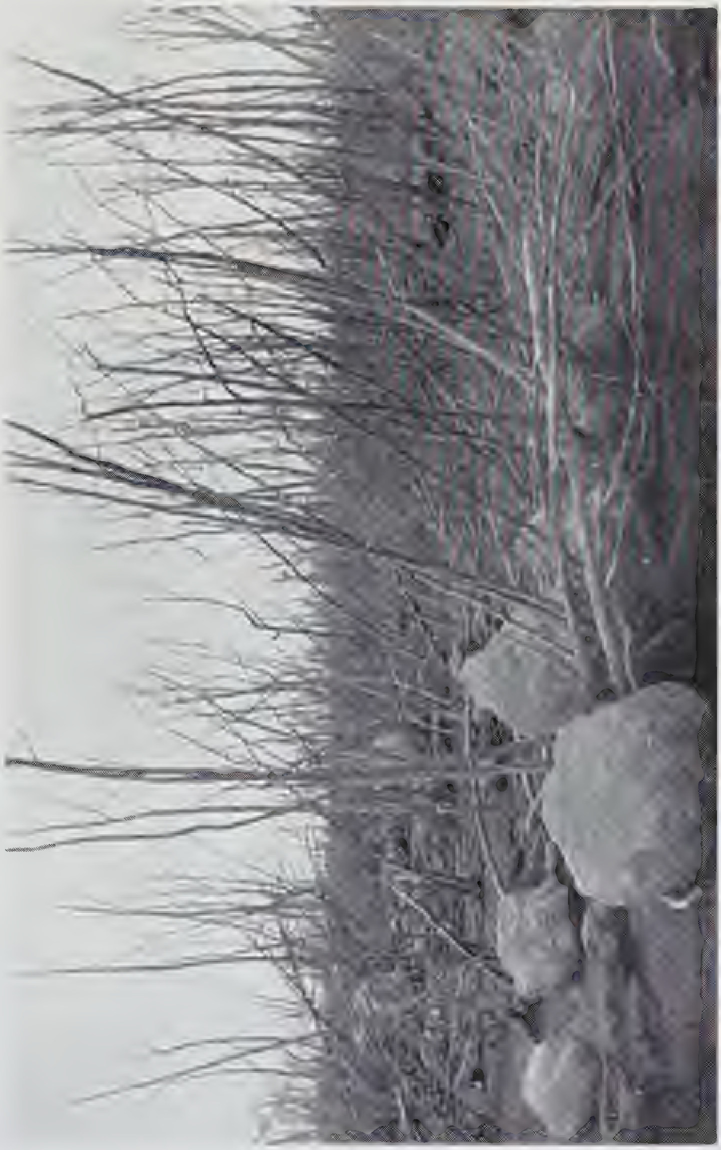


Fig. 22 *b* - Traces of a lahar on its margin, April, 1956.
(Photograph by the author).

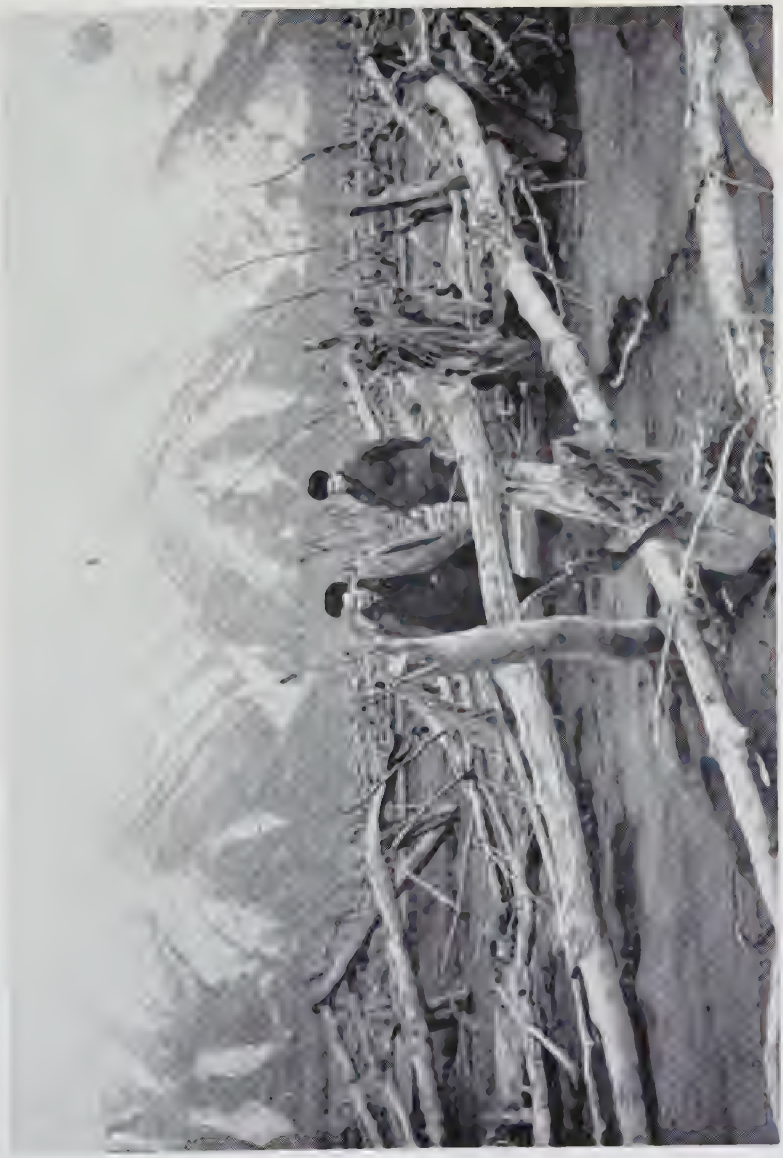


FIG. 23 - Felled forest in the valley of the river Bolshaia Hapitsa.
(Photograph by N. K. KLASSOV).

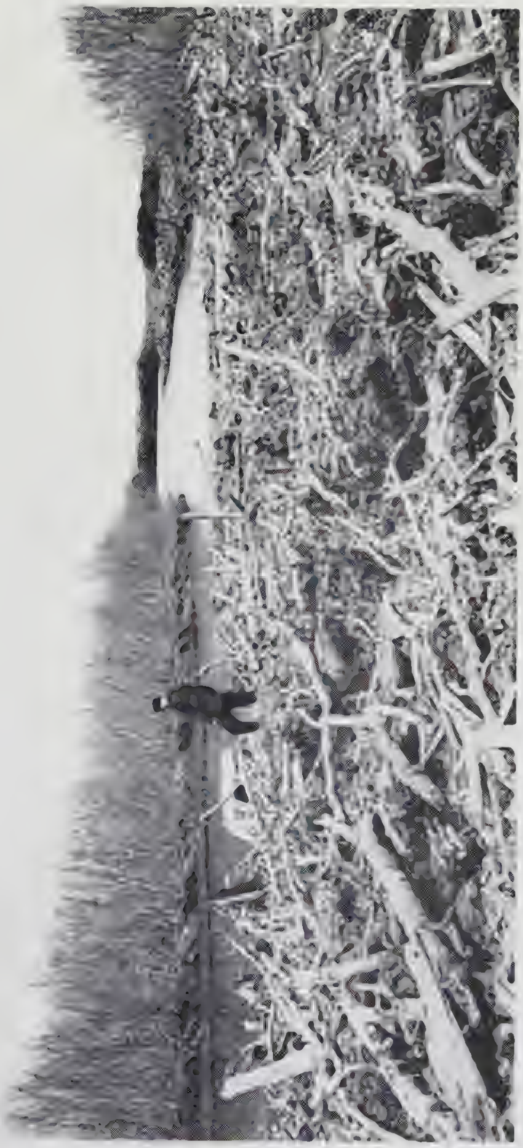


Fig. 24 - Trees piled up at the end of the lahar.

(Photograph by the autho

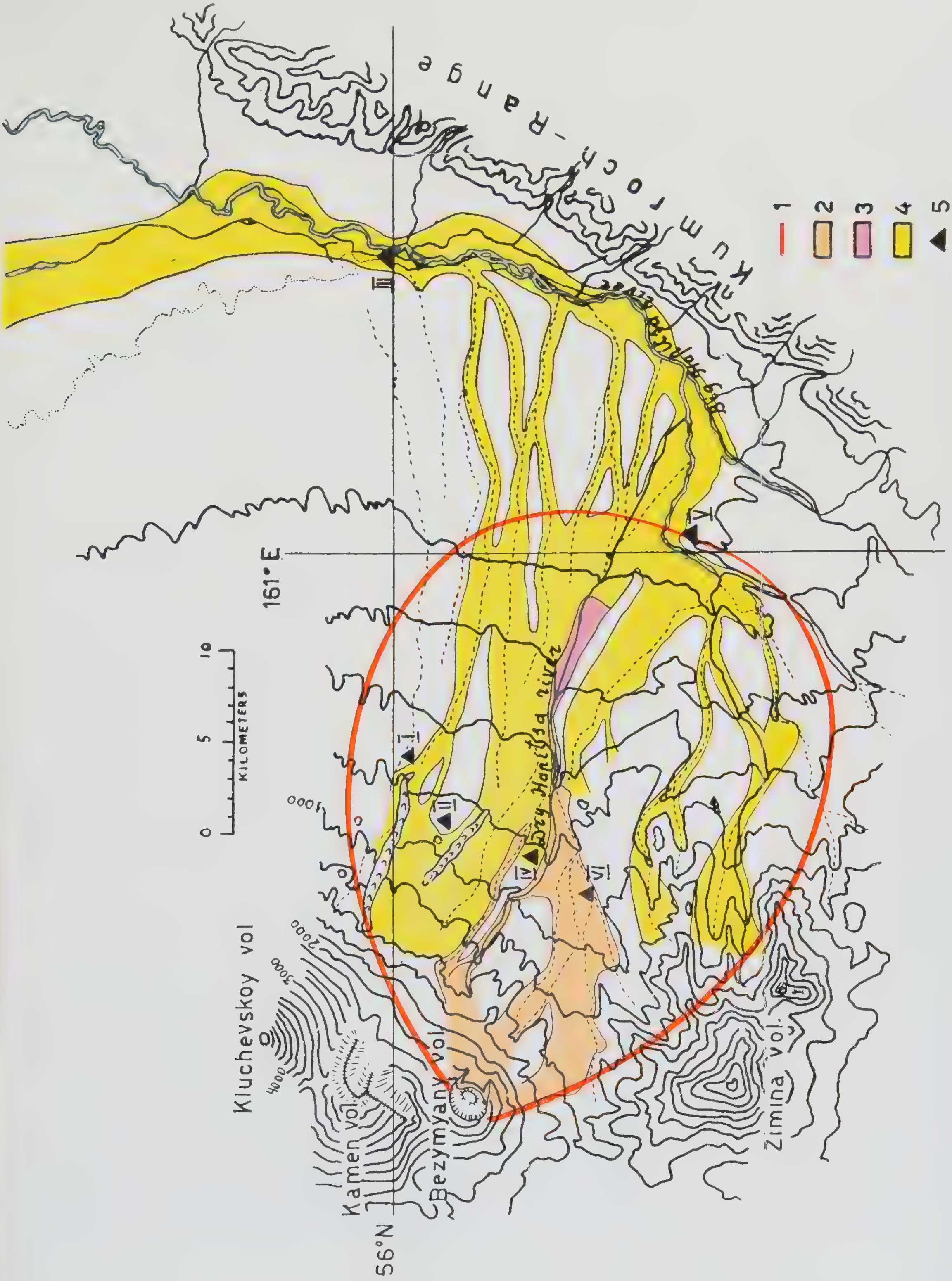


FIG. 25 - Sketch of the territory embraced by the explosion of March 30, 1956. 1 - boundary of the area ruined by the explosion, 2 - agglomerate flow, 3 - mud deposits, 4 - routes of mud flows, 5 - expedition camps.

(Compiled by the author).

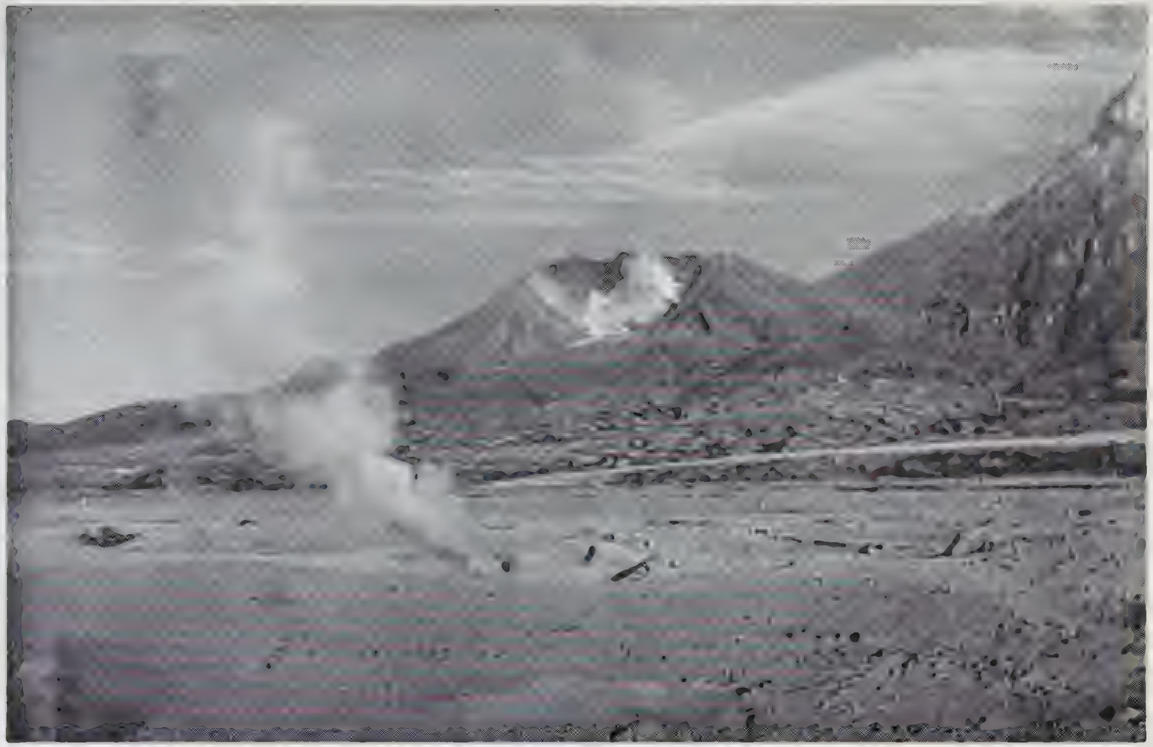


FIG. 26 - Bezymianny volcano. View from the agglomerate flow in August, 1956.
(Photograph by the author).

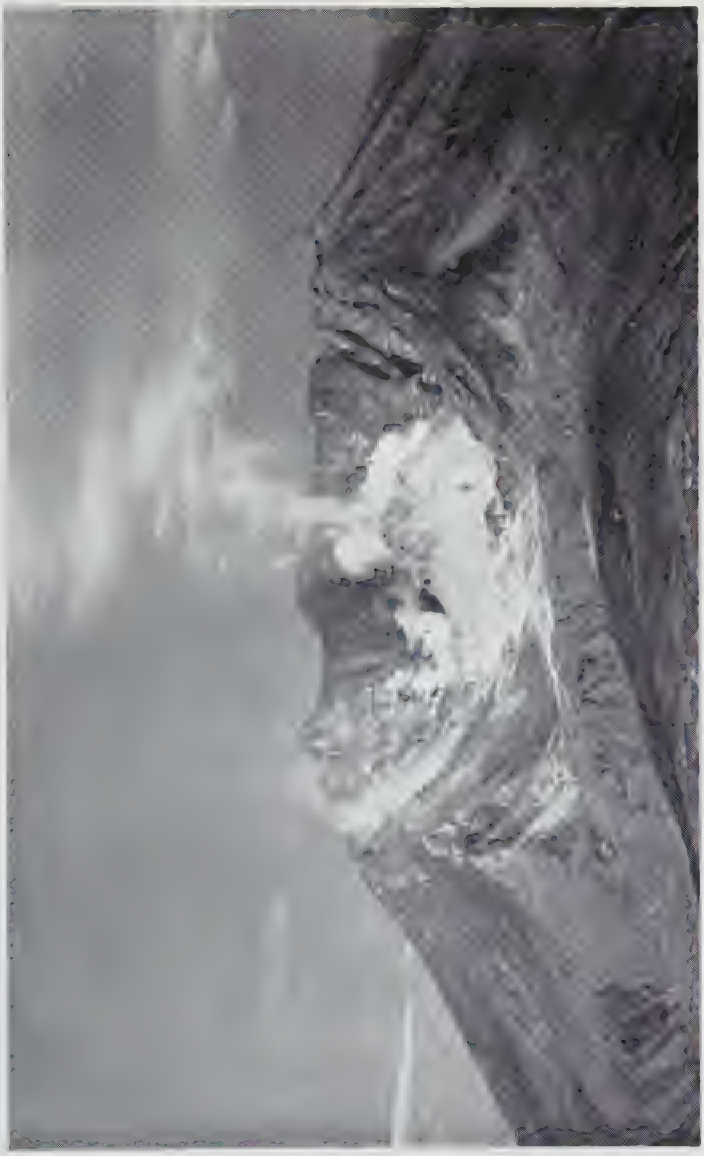


Fig. 27 - Dome in Bezymianny crater in August, 1956.

(Photograph by the author)

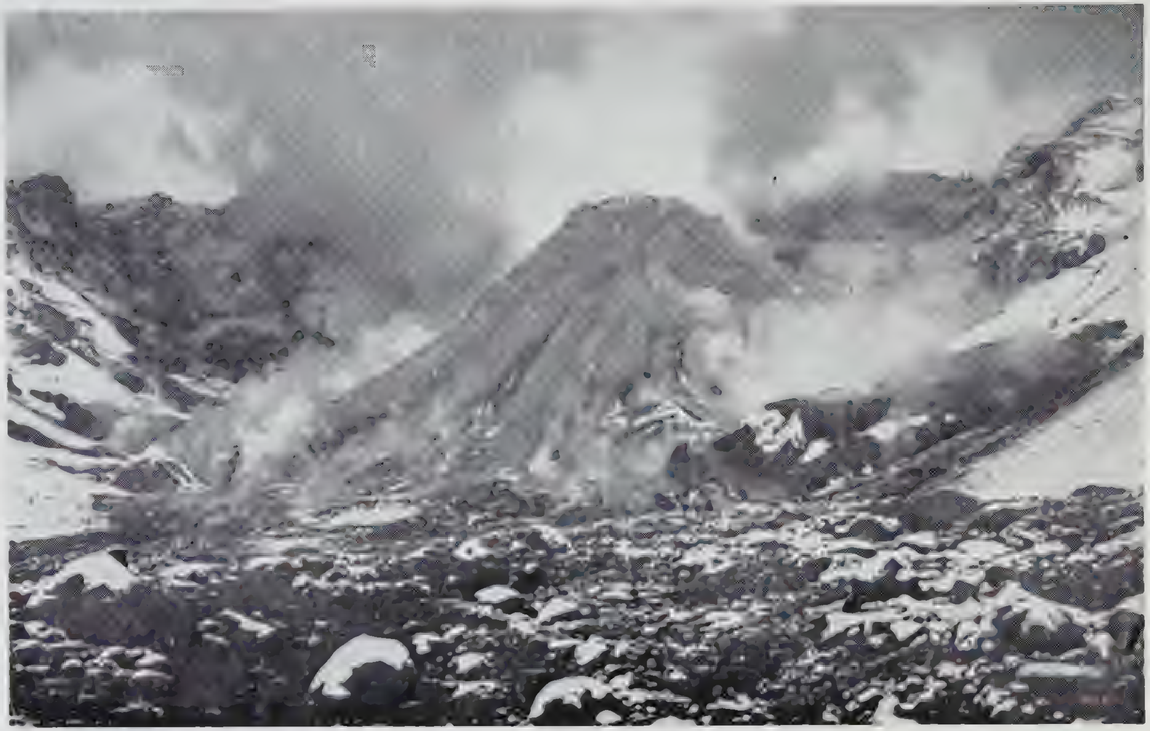


Fig. 28 - In Bezymianny crater on August 27, 1956.
(Photograph by the author).

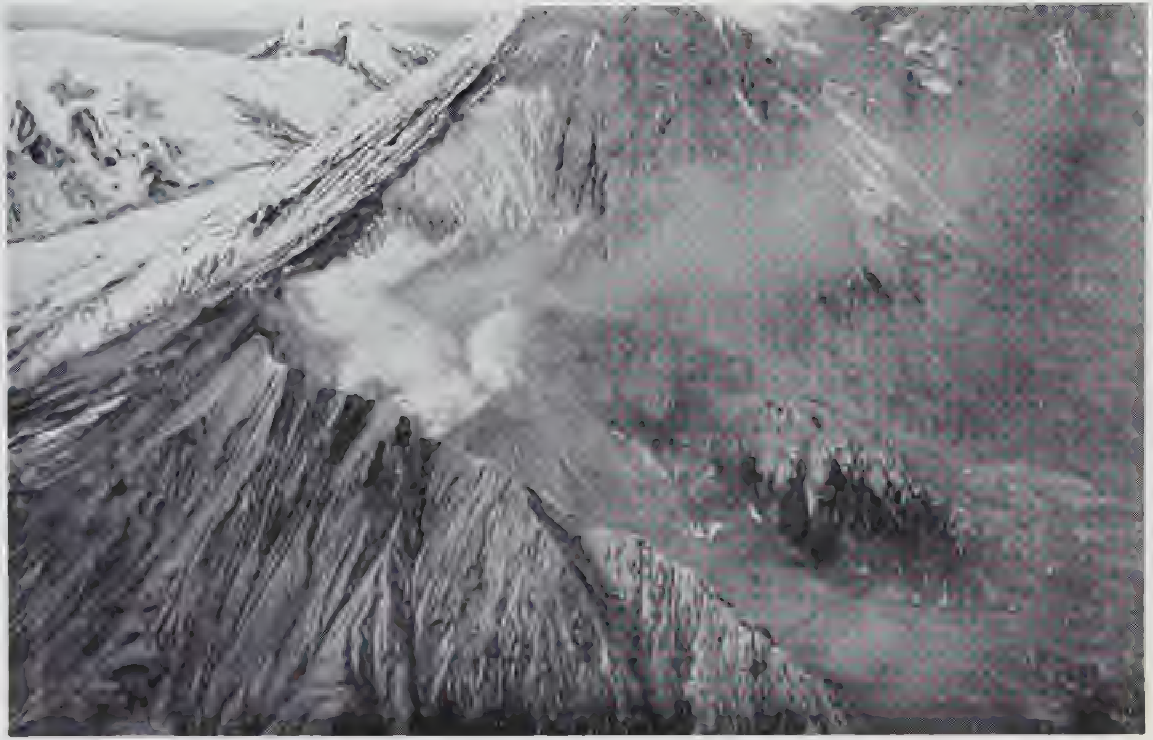


Fig. 29 - Bezymianny volcano in October, 1956.
(Airphotograph by the author)

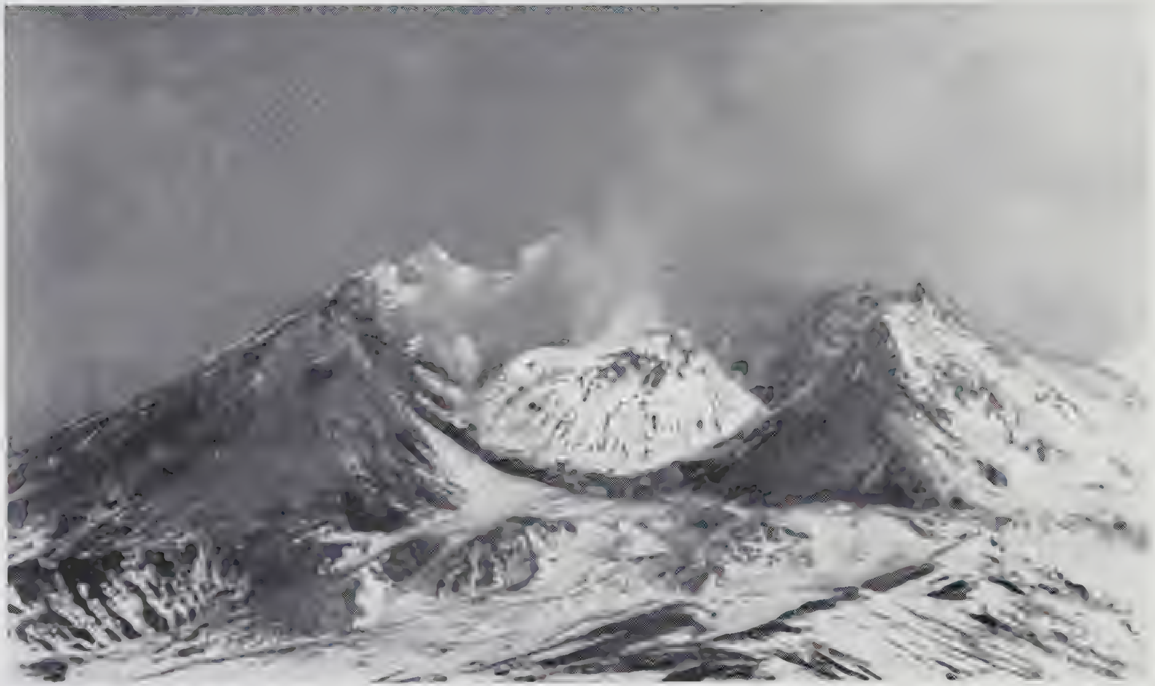


FIG. 30 - Dome in Bezymianny crater after the end of the eruption, May, 1957.

(Photograph by the [illegible])

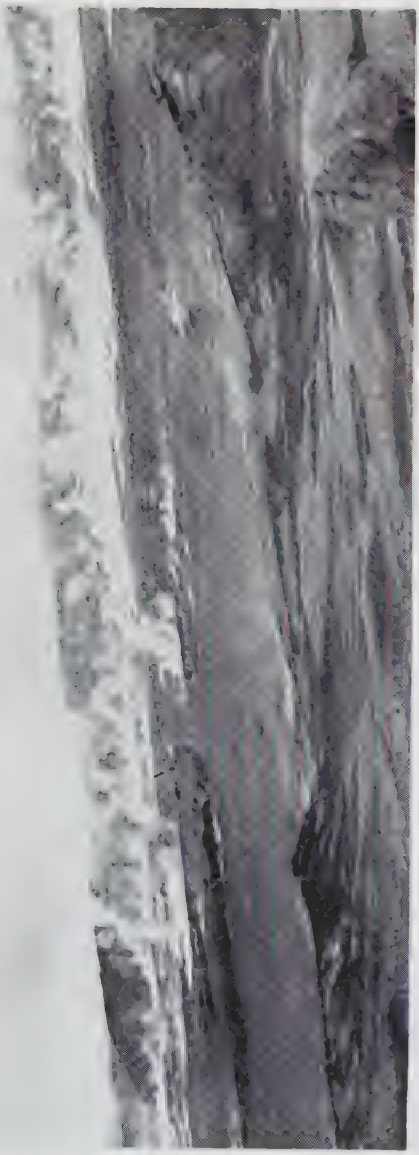


Fig. 31 - « Valley of Ten Thousand Smokes of Kamchatka », April, 1956.
(Photograph by the author).

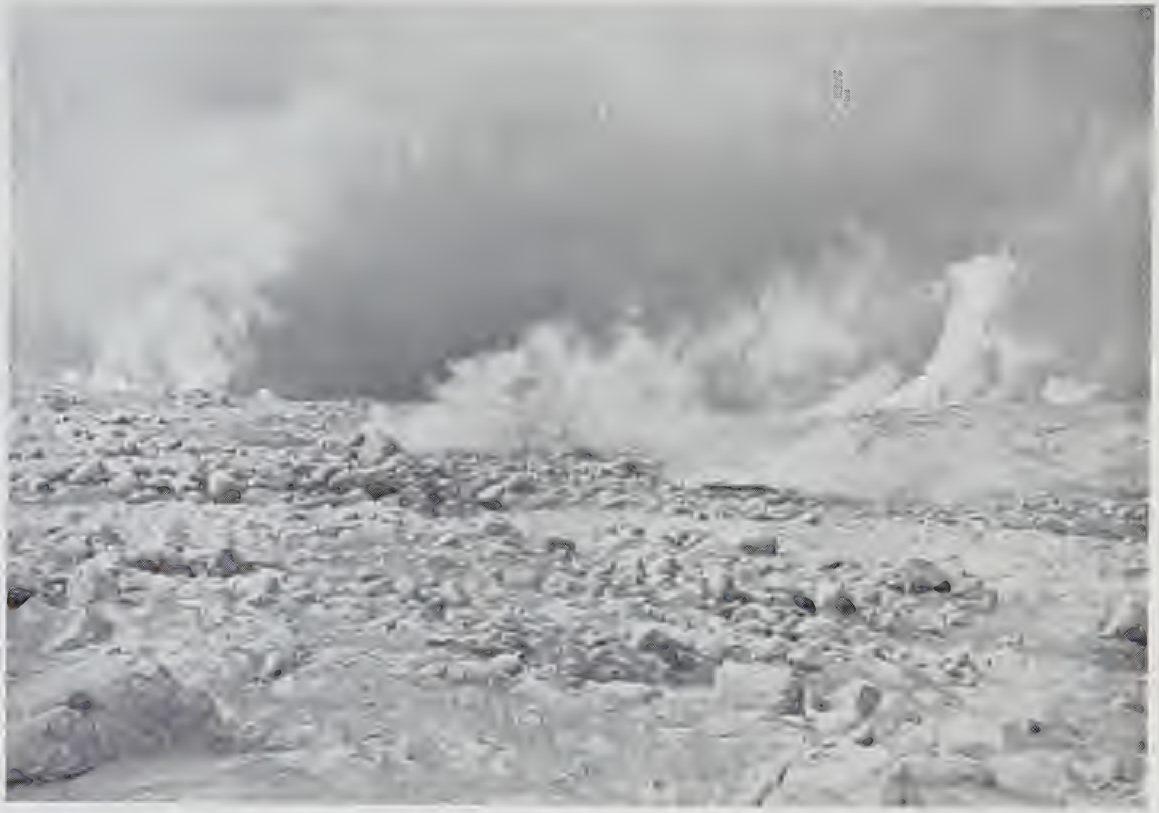


Fig. 32 - Surface of the agglomerate flow. April, 1956.

(Photograph by the author).

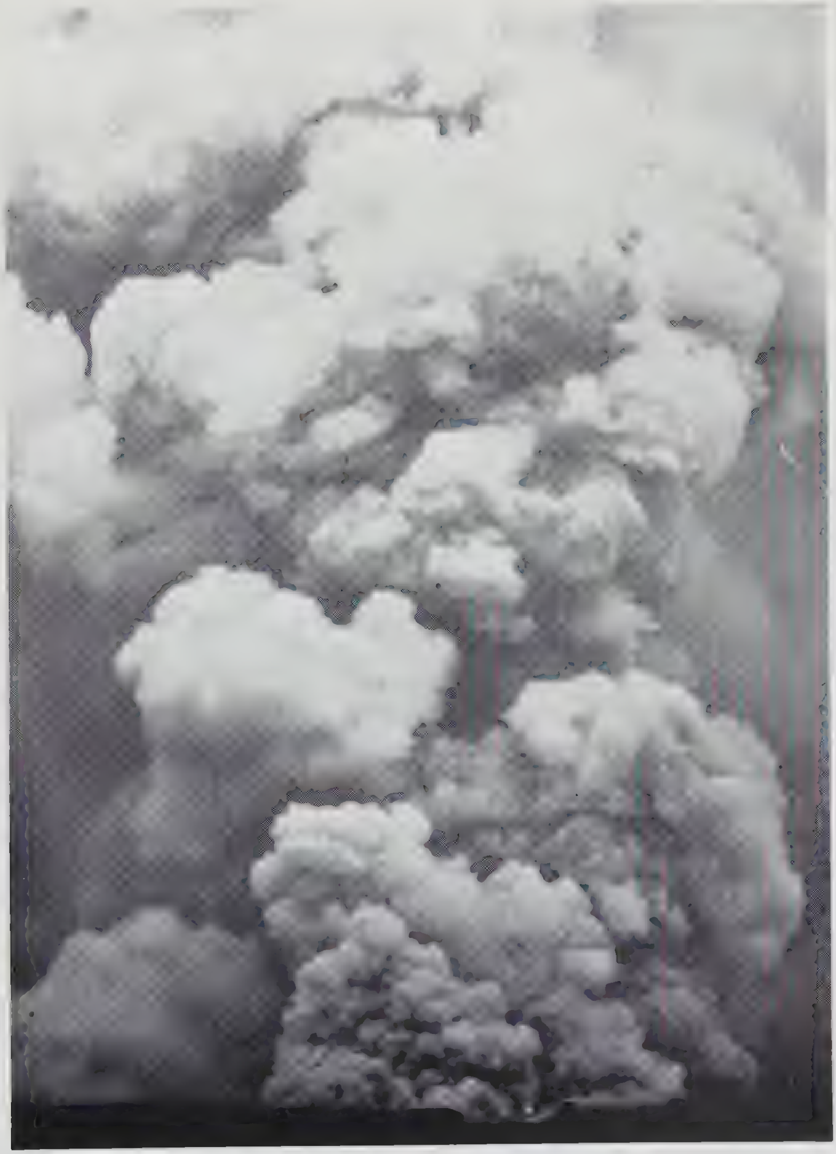


FIG. 33 - Secondary eruption on the agglomerate flow. August, 1956.

(Photograph by the author).

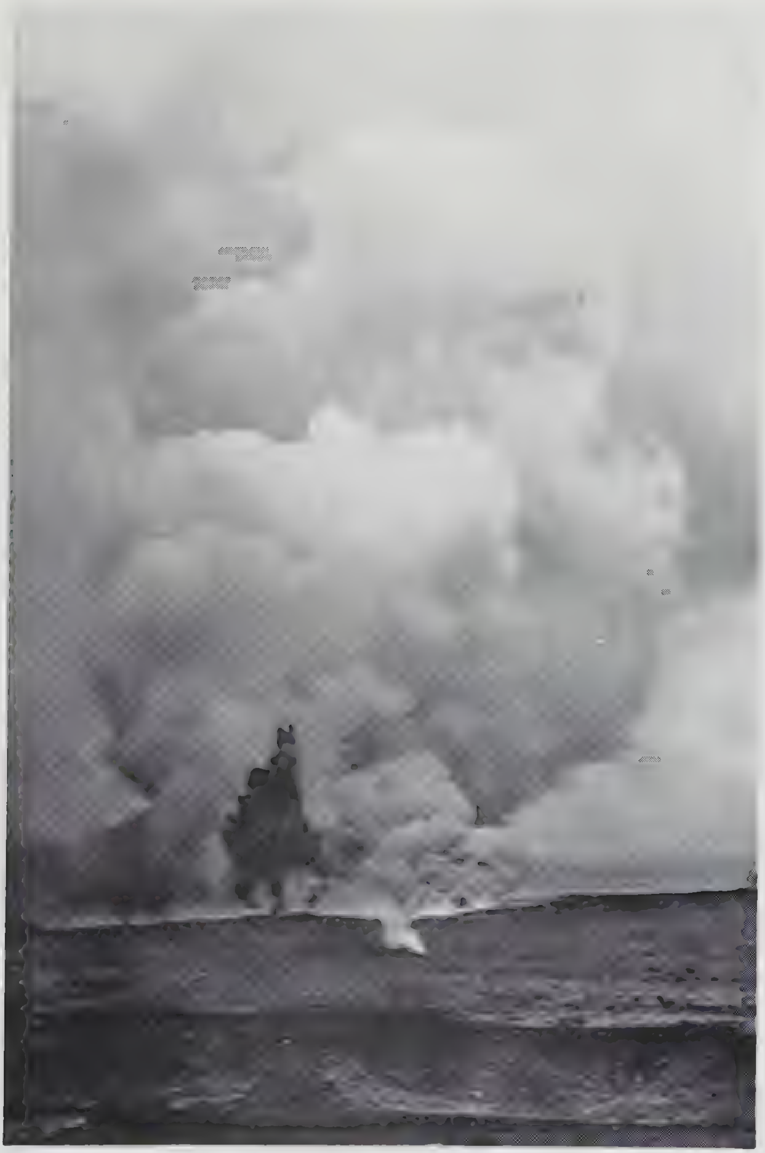


FIG. 34 - Secondary eruption with a fountain of liquid mud. August, 1956.

(Photograph by the author).

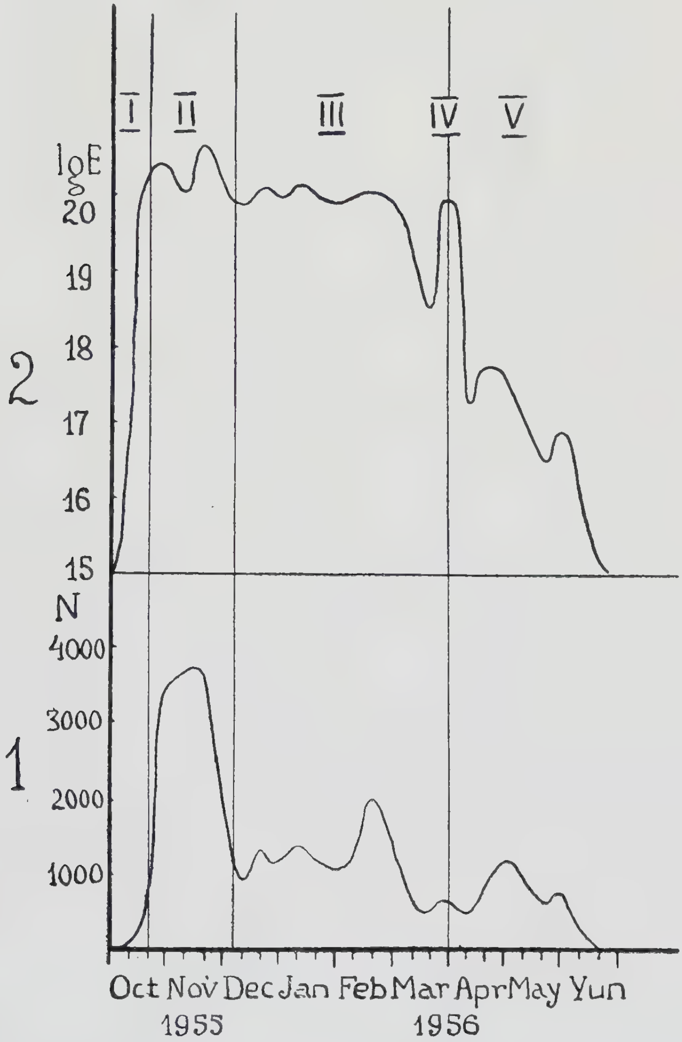


Fig. 35 - Diagram showing changes in the number (1) and energy of earthquakes (2) in the course of the eruption. Roman figures show periods of eruption.

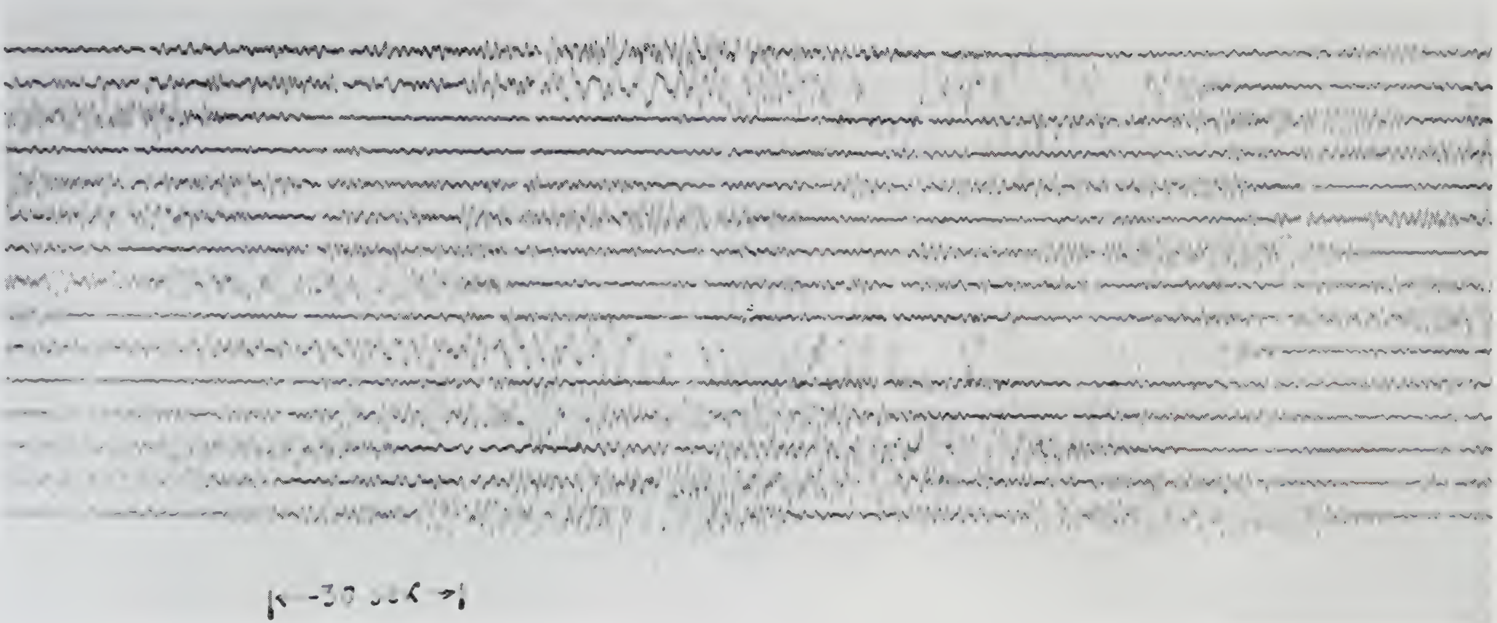


Fig. 36 - Volcanic earthquakes, associated with Bezymianny eruption. Records of Kirnos seismographs. November, 1955.

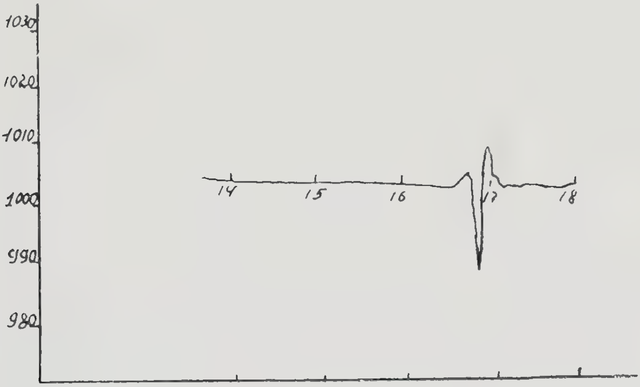


FIG. 37 - Record of the explosion on March 30, 1956, barogram of Kliuchi meteorological station.

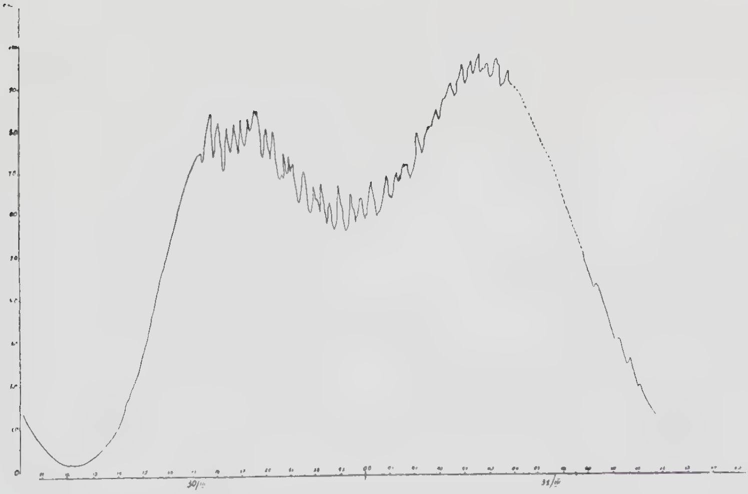


FIG. 38 - Seiches on March 30-31, 1956 in the mouth of river Kamchatka (maregraph record). Reading from conditional zero.

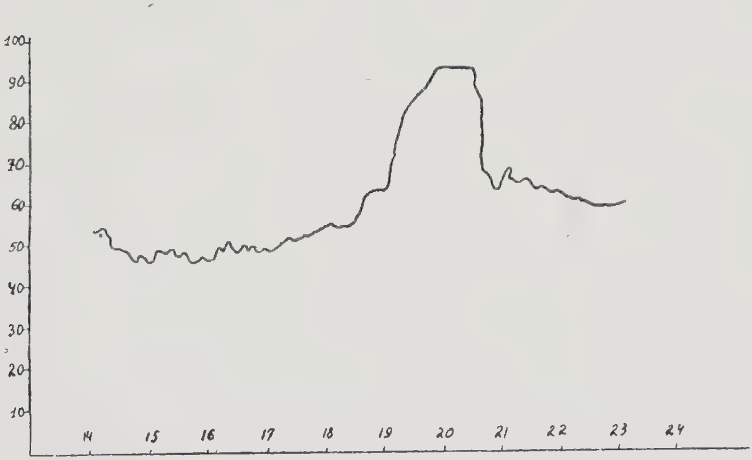


Fig. 39 - Change in the air humidity in Kliuchi during the ashfall on March 30, 1956.

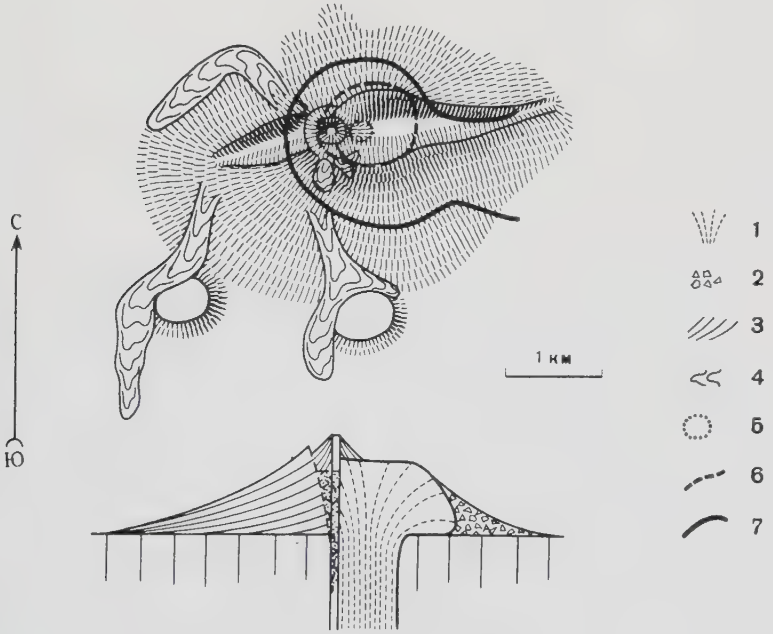


Fig. 40 - Sketch of Bezymianny volcano structure.
1— old dome, 2— brèches d'écroulement, 3— Stratovolcano, 4— lava flows, 5— crater in October, 1955, 6— crater in January, 1956, 7— crater after the explosion of March 30, 1956. (By the author).

Academy of sciences of the USSR
THE NATIONAL COMMITTEE FOR GEODESY
AND GEOPHYSICS
Section of volcanology

V. I. VLODAVETZ

On the underground structure of some Volcanoes on Kamchatka

(With 1 plate)

The geological structure of volcanoes and of their nearest surroundings as well as the shape of their aboveground forms gives a general idea about their structure in the depths.

Openings of the main and lateral volcanic vents (determined by the presence of craters, explosion funnels, domes and dikes), the structure of faults, sometimes occurring on volcanic bodies, as well as exposures disclosed by processes of erosion, permit to solve the question regarding the underground structure of a certain volcano or at least to have some idea about it.

Numerous examples evidence that while some volcanoes have very simple forms of volcanic structure, others are much more complicated. Even in one volcanic region or one part of it, like in northern Kamchatka, for instance, there are volcanoes with very varied aboveground forms, which indicates a difference in their underground structures. Among volcanoes with a more complicated underground structure are active volcanoes Kliuchevsky, Plosky Tolbachik, Zentralny Semiachik, Sheveluch, Uzon, Maly Semiachik, Karymsky and some others.

Zentralny Semiachik is a ruined basaltic cone with two craters, on the body of which and next to it there are 16 andesitic domes, located along five parallel lines of a northeastern trend with two branches going off in a northwestern direction.

Sheveluch is a basaltic and andesitic volcano, having a shape of a relatively gently sloping cone with a sector graben in its southern part. In this graben there are radially located basalt dikes and laterally placed andesite domes. The latter are also found on the southwestern flank of the main cone in a row stretching in a north-northwestern direction — along a line approximately parallel to the line of the southwestern limb of a fault of the sector graben. One dome is located on the end of the southeastern limb of the fault of the same graben.

The Karymsky dacitic cone-like volcano is located in a caldera, which truncated the adjoining Dvor volcano, built of lavas of a basaltic to andesitic composition. In the central part of Dvor volcano, in the wall of a fault formed by the caldera, there is a small pipe-like outcrop of dacite, which is, apparently, an offshoot of the main channel of ascent in the Karymsky volcano.

Thus the question of the underground structure of ordinary volcanoes is solved, in the majority of cases, easily and simply, while the problem of the roots of complex volcanoes is more difficult and on many occasions different solutions are being offered.

Usually the routes of volcanic channels are mainly determined by local volcanic and tectonic dislocations and partly by regional tectonic fractures.

The present paper attempts to establish the underground structure of Kliuchevsky volcano, characterized by an abundance of lateral craters.

Kliuchevsky, a predominantly basaltic volcano, is a slightly truncated cone with numerous lateral craters on the northeastern, eastern and southeastern flanks, located mainly along 12 radii and, supposedly, along 3 arcs. The length of the radii is from 6 to 18 km and each of them includes from 3 to 11 craters and explosion funnels. The length of the arcs is from 4 to 20 km and embraces from 5 to 9 cones. The distance from the lateral craters to the main channel is from 7 to 20 km. In addition several cones are located outside the above mentioned lines. There is also one radial dike.

Such a location of lateral craters along radii and arcs raises a question regarding the underground structure of this volcano. Is the arcwise and especially the radial location of craters associated with deep fractures, reaching the volcanic hearth, or is such a location of the craters associated with a subsurface injection of lava along the routes going from the upper or deeper parts of the main channel?

It is usually assumed that the channels of lateral forms (craters, cones, domes or their groups and some of the dikes) of a complex volcano can be:

1) offshoots of the main volcanic channel: a) descending and b) ascending;

2) independent channels, going from the volcanic hearth, and

3) lateral channels nearest to the main channel being offshoots, emerging from the main channel, while the more distant lateral channels are directly connected with the volcanic hearth.

In order to try and solve the question regarding the underground structure of Kliuchevsky volcano we compared data obtained by S. I. Naboko during the eruption of Kliuchevsky volcano in 1937-1939 with the generally accepted course of a normal process of differentiation in a basaltic magma, as a result of which more acid derivates are being formed in the upper section of the magmatic hearth and more basic ones — in the deeper parts.

Such a character of differentiation is illustrated by many examples. Among the last examples of such kind could be the changes in the composition of lavas registered in the observations of S. Thorarinsson during the latest eruption of Mt. Hekla. Pumice ejected during the first hour of eruption contained 62 % of SiO_2, while ashes which have been emitted several hours later contained 57-58 % of SiO_2. Lava which was poured out five months after the beginning of the eruption contained 55.4 % of SiO_2, and lava which flowed out a year after the beginning of the eruption contained 54.25 % of SiO_2.

A similar picture was observed at Kliuchevsky volcano. Data on the eruption of 1937-1939 were taken as a basis for the deductions made below. During this eruption lava was first flowing from the main (summit) crater and later, early in February 1938, within a few hours several lateral craters burst open on the eastern flank of the volcano. These craters were located in a row on a radius, the highest at about 1900 m and the lowest at 900 m.

Volcanic activity of the highest craters stopped rather quickly, but the lowest was active for over a year and lava was flowing out very often.

The chemical and partly the mineralogical composition of these lavas did not remain the same. It was changing both in lavas which flowed out at different heights and also in those which were flowing out of the same crater. These changes are illustrated by the following table:

Name of crater	Height of the point of issue in m	Crater distance from main channel (in km)	Time of outflow	SiO_2 content (in %)	Note
Main crater	4800	0	May, 1937	54.48	
Kozei	1800	8	February, 1938	53.93	
Trety	1260	12	February, 1938	53.48	
Tiranus	1000	14	February, 1938	53.17	
Biliukai	900	15	February, 1938	51.03	from the first portions of lava
»	900	15	February-March, 1938	52.08	average of several outflows
»	900	15	June-July, 1938	52.84	»
»	900	15	August-September, 1938	53.24	»

These figures establish two indisputable facts: 1) lower acidity of lavas with a lower place of outpouring and 2) gradual increase in the acidity of lavas, which flowed out of the same crater.

It should consequently be assumed that in the upper part of the main channel or volcanic hearth there was lava of a changing composition - from 54.5 % SiO_2 at the very top and up to 51 % SiO_2 at the bottom (to be more precise at the lowest horizon of the outflow of lava).

These facts go to show that magma is not uniform in the volcanic hearth and is subject to differentiation. But in this paper we are not interested in the differentiation of magma, we are concerned with the underground structure of Kliuchevsky volcano. That is why we should make use of these observations on the changes in the composition of lavas for the establishment of the underground structure of the volcano.

The radial and partly arcwise position of lateral craters proves the occurrence in the body of the volcano of fractures in which channels were formed, but how they are situated could only be surmised.

Here are the main of these surmises:

1) lavas and other volcanic products had burst from the main channel first along one of the lateral channels, and then, not far from the surface of the earth, have branched into a number of channels;

2) each lateral crater is connected with the main channel by a separate lateral channel;

3) each lateral crater is connected by separate channels with the upper part of the volcanic hearth.

The suggestion that during an outpour at first one channel is followed which later branches into several ones contradicts to the above mentioned generally accepted idea on the differentiation of magma.

As more plausible explanation of the described change in the composition of lavas by height and time of outflow would be the acceptance of the existence of separate channels going from different horizons of the upper part of the volcanic hearth or main channel, if the latter is a big one. It should be remembered that during the 1937-1939 eruption of Kliuchevsky volcano a considerable volume of lava was poured out and ejected (about 0.5 cubic km).

As the table shows, the first outflows of lava from the main crater were the most acid and contained in rounded figures 54.5 % of SiO_2 (length of the flow about 3 km).

Later lavas flowing out of the lateral craters at short intervals one after the other had a varying composition - the lower the point of issue of the lateral channel, the more basic was the lava composition. So, for instance, lava from the lateral crater Kozei contained 54 % SiO_2, lava from the lateral crater Trety, situated 540 m lower, contained 53.5 % of SiO_2 (length of the flow 250 m), and lava which flowed out of the lateral crater Tiranus, located 260 m below the preceding crater, contained 53.2 % of SiO_2 (length of the flow 1 km). Finally one of the first portions of lava, which had flowed out of the lowest crater Biliukai, 100 m below Tiranus, contained 51 % of SiO_2 (total length of the flow 16 km).

Until this moment the change in the composition of lavas was proceeding in the same direction, which is often observed in other volcanoes, like, for instance, in the above mentioned Hekla volcano. The same procedure took place during the 1945 eruption of already mentioned Kliuchevsky volcano. On the southeastern flank of this volcano a row of lateral craters burst open and here, according to B. I. Piip, changes in the composition of lavas were observed analoguous to those which took place during the first stage of the eruption of this volcano in 1937-1939. Bombs from the topmost crater Iubileiny were more acid than the first portions of lava from the lowest crater, and the latest portions of lava (from the lowest crater) were more basic than the first, i.e. a regular decrease in acidity of lavas by height and time of their outflow could be observed.

As to the lavas of 1937-1939 eruption, their further change in composition went in a reverse order. The acidity of lavas began to increase. Lava was poured out during more than a year only from the lowest crater Biliukai and the average SiO_2 content in lavas which flowed out 1-2 months after the beginning of the eruption of Biliukai was 52 %, in 5-6 months - 52.8 %, and in 7-8 months - 53.2 %. The observed increase in the acidity of lavas could hardly be explained by processes of assimilation.

If the changes in the composition of lavas which have been registered during the first stage of eruption, approximately until the middle of February, 1938, could be explained by the following in time and gradual in their expanse outflows of a somewhat differentiated (vertically) lava along one or several lateral channels emerging from the main channel or the upper part of the volcanic hearth, the reverse change in the composition of lavas observed during further outflows from the lowest crater, could be explained by the presence of only separate lateral channels, branching off from the upper part of the volcanic hearth or from the main channel, if it is of a big size.

As lava was flowing out of the lowest crater, apparently connected by a separate channel with the lowest (relatively in that case) horizon of the volcanic hearth, an ever more and more acid magma was coming up to this channel from the upper part of the hearth (as also thought S. I. Naboko). This is the only possible explanation of the above mentioned change in the composition of lavas.

In such a way, putting together all these events, it is possible to formulate some conclusions regarding interrelations between some of the phenomena of these eruptions and the peculiar characteristics in the composition of lavas as well as the underground structure of the volcano.

Such a sequence in the changes of composition of lavas flowing out in space and time during the eruption of 1937-1939, could be explained only by the existence of separate lateral channels. This means that the underground structure of Kliuchevsky volcano consists of separate channels (situated in radial or arcwise planes of fractures), branching off from the upper part of the volcanic hearth.

BIBLIOGRAPHY

VLODAVETZ, V. I. - *Kliuchevskaia group of volcanoes.* Trans. Kamchatka Volcanol. Station, 1940, v. 1. (In Russian).

VLODAVETZ, V. I. - *Kliuchevsky volcano.* Zemlevedenie (Soil science), 1940, v. 1 (41). (In Russian).

NABOKO, S. I. - *Products ejected by Kliuchevsky volcano in 1937-1938.* Trans. Laborat. of Volcanol. and Kamchatka Volcanol. Station, 1947, v. 4. (In Russian).

NABOKO, S. I. - *Eruption of Biliukai, satellite crater of Kliuchevsky volcano in 1938.* Trans. Laborat. of Volcanol. and Kamchatka Volcanol. Station, 1947, v. 5. (In Russian).

PIIP, B. I. - *Kliuchevskaia sopka and its eruption in 1944-1945 and in the past.* Trans. Laborat. of Volcanol., 1956, v. 11. (In Russian).

THORARINSSON, S. - *The eruption of Mt. Hekla, 1947-1948.* Bull. volcanol., Sér. II, Tome X, Napoli, 1950.

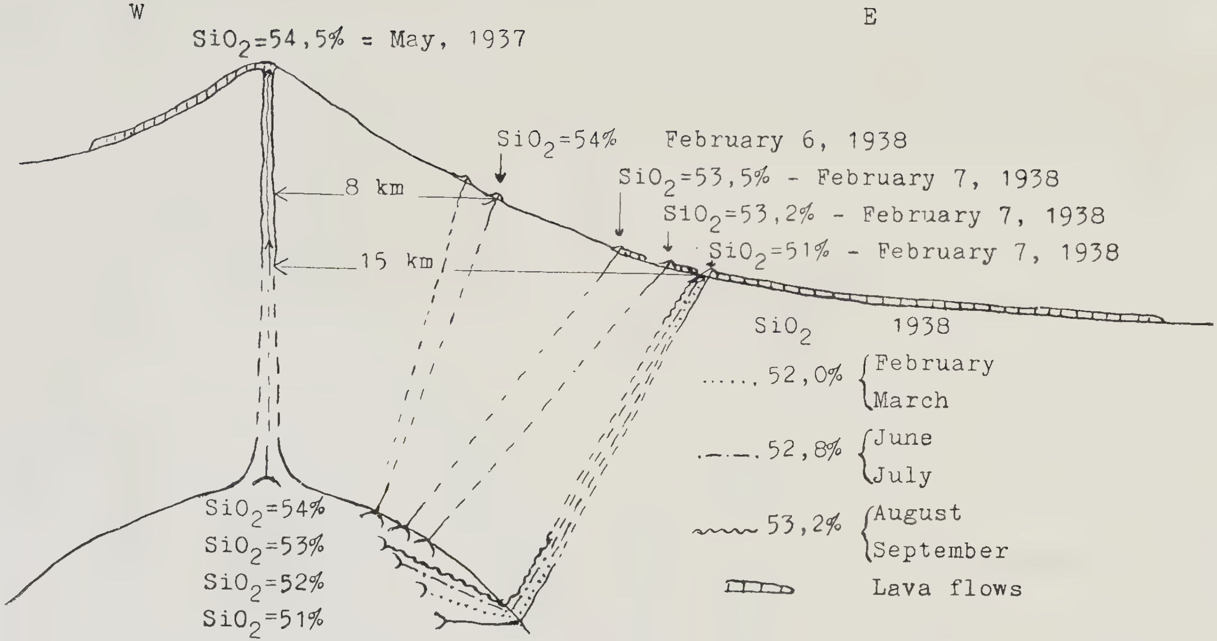

W
E
SiO_2=54,5% = May, 1937
SiO_2=54% February 6, 1938
SiO_2=53,5% - February 7, 1938
SiO_2=53,2% - February 7, 1938
SiO_2=51% - February 7, 1938
8 km
15 km
SiO_2=54%
SiO_2=53%
SiO_2=52%
SiO_2=51%
SiO_2 1938
52,0% February March
52,8% June July
53,2% August September
Lava flows

FIG. 1 - The scheme of the distribution of the volcanic channels in Kliuchevsky volcano composed on the base of the distribution of lateral craters and the alteration of chemical and mineralogical compositions of the lavas in space and time.

Academy of sciences of the USSR
THE NATIONAL COMMITTEE FOR GEODESY
AND GEOPHYSICS
Section of volcanology

S. I. NABOKO

Volcanic exhalations and products of their reactions as exemplified by Kamchatka-Kuriles volcanoes

A systematic study of volcanic exhalations of Kamchatka volcanoes has started since 1935, when a volcanological station has been organized on Kamchatka (A. N. ZAVARITZKY, V. I. VLODAVETZ, I. Z. IVANOV, L. A. BASHARINA, N. D. TABAKOV, B. I. PIIP, S. I. NABOKO).

On the example of eruptions of Kliuchevsky volcano and a burst on its flanks of lateral craters in 1938 (Biliukai), 1945 (Iubileiny proryv), 1946 (Apakhonchich) etc. with outflows from them of basaltic lavas, Sheveluch in 1945-1949 with the formation of an andesitic dome, solfataras and hydrosolfataras of Koshelev and Kikhpinych volcanoes on Kamchatka, Golovnin and Mendeleyev on Kunashir island and a number of thermal springs, we have studied exhalations of different stages of cooling of lava masses and the products of their reactions with the atmosphere, waters and rocks.

Judging by numerous analyses of fumarolic gases of Kamchatka-Kuriles volcanoes, their magmas contain the same volatile components. However, their quantitative ratios for different volcanoes and at different stages of their activity vary. Basaltic magma of Kliuchevsky volcano at the present stage of its evolution is rich in chlorine and fluorine; andesitic magma of Sheveluch is rich in sulphur and that of Avacha - in boron. An example could be the lengthy cooling of basalt, which flowed out in 1938 from the lateral crater Biliukai of Kliuchevsky volcano. During its first high-temperature stage in fumarolic gases all the main easily volatile components were present, but they were enriched by hydrogen, as possessing the greatest migratory capacity. With the cooling of lava masses on the background of predominating water vapours, haloids and gas first diminished and then stopped of emanating; they were getting substantially sulphurous and carbonated, then sulphurous gases became carbonated. During the last stage mainly water vapors were emanating. Such a change in the composition of exhalations in time was determined by the degree of volatility of individual components and their concentration in the magma. Haloid gases, as the most volatile, active and available ones in the magma in a subordinate amount as compared to carbonated and sulphurous gases, disappear first. When gases are disengaged from the magma at a certain depth, as it took place when explosive craters were formed on the flank of Kliuchevsky volcano in 1938 and 1945, the composition of their exhalations were sharply different from exhalations from the basalt which was poured out of the neighbouring craters. They were essentially sulphurous and carbonated; haloid gases were practically absent; as the most active ones, they were, apparently, spent on reactions with rocks and waters on their way to the surface.

Throughout the entire volcanic process water steam forms the main component of volcanic gases. After steam, as well as nitrogen and oxygen, which are mostly atmospheric impurities, the first place by quantity belongs to gases of the carbon group. In high temperature fumaroles, in dry gas, after nitrogen and oxygen are excluded, the amount of carbon monoxide comes to 40 %, in solfataras of carbon dioxide - 95 %, in mofettes - 100 %. Next comes sulphur; in gases it appeared as S, H_2S, SO_2, COS and maybe SO_3. In high-temperature fumaroles SO_2 was determined, in fumaroles of lower temperatures it could also be H_2S. If they were present simultaneously, their amounts were not constant at the expense of oxidation and reduction reactions. Chlorine and fluorine, being characteristic volatiles of a magma, saturate it by far not uniformly. The disengagement of chlorine as compared to the disengagement of sulphurous and carbonated gases is not lengthy and indicates the active period of magma and its first exhalations. A big role in exhalations belongs to hydrogen, which in high-temperature fumaroles comes to 50 % (in dry gas without N_2 and O_2).

High temperature gases from Kliuchevsky volcano basalt had often a reducing capacity owing to a predominance in them of CO and H_2 (up to 70 %). Lower-temperature gases possessed an oxidizing capacity, because of a predominance in them of acid gases.

On the surface of the Earth exhalations reacted with oxygen of the air, as a result of which their composition sharply changed. In fumaroles of the highest temperature H_2, CO, S, H_2S were combusted; under lower temperatures H_2S oxidized up to elementary sulphur, SO_2 up to sulphuric acid; a number of other transformations took also place, as a result of which a new equilibrium was established in the gases.

Most intensely gas distillation was proceeding during the first high-temperature stage of lava flow. In compounds with easily volatile components metals were also volatilized from the lava. Judging by the sublimates, during the eruptions of Kliuchevsky volcano, when basaltic and andesite-basaltic lavas were flowing out at temperatures of 1000-800° and down to 500°, alkaline metals (Na and K) were volatilizing out of these lavas in compounds with chlorine. This happened in the same proportion in which they have occurred in the original lava (Na : K : 3 : 1).

In visible quantities iron chloride was flying out of basalt, becoming part of sublimates formed (erythrosiderite and kremersite). Aluminium, magnesium and calcium in compounds with chlorine were flying in insignificant quantities and only sometimes could be qualitatively determined in the first products of exhalations.

Among microelements which were volatilizing from basalt in weighable quantities was copper chloride. Around gas jets sublimates of atakamite and oxychloride of copper were precipitated. Copper concentration in some sublimates, as compared to its concentration in basalts, increased up to 6000 times (in some sublimates there has been up to 60 % of copper). In sublimates of chlorides Li, Be, Pb, Sn, Ag, Zn, Co, Ni, Zr, Mo, Bi, Ga, Te, Cr, V, Ba and Sr were found in greater concentrations than they had in the lava.

Si and Fe very intensely escaped from basalts and andesite-basalts of Kliuchevsky volcano in compounds with fluorine.

In compounds with sulphur, just as with chlorine, at temperatures of 900-800° from andesites of Sheveluch Na and K were the first to escape, but in a different proportion, than in the lava. Sodium sulphide was escaping more intensely that potassium sulphide and while the proportion in the lava was Na : K = 3 : 1, in the products of a direct sublimate - in sulphates it became Na : K = 20 : 1. At temperatures above 500° potassium was flying as a sulphurous compound out of andesite-basalts of Kliuchevsky volcano and anhydrite was profusely precipitating from gases on the surfaces of incandescent fractures in explosive craters of Kliuchevsky volcano. Among the products of direct sublimates from Sheveluch andesites up to 5 % of CaO and up to 2 % of MgO have been determined. Among ore elements vanadium was escaping with sulphurous gases from Sheveluch andesites and its concentration in sublimates which precipitated from glowing clouds increased compared to lava 1200 times (in some sulphates up to 12 % V_2O_5 was determined). In small quantities were flying sulphurous compounds of Be, V, Cr, Ni, Zn, Ga, Sr, Zr, Mo, Sn, Ba and Pb.

During the cooling of andesitic and basaltic masses changes in the volatile constituents were observed.

The first exhalations were always richer in metals, than the following ones. In sublimates of Iubileiny proryv, which formed during the first year, exhalations contained more often Be, As, Te, Pb, Cu, Ag, Ni, Zr, Bi, Ga, Tl, Cr, V, Ba, Sr and Sc than exhalations of the second year.

In sublimates of the same period but collected from lava flows in different stages of cooling the concentration of microelements was in direct proportion to the age of the flows.

In sublimates of Apakhonchich basalt during the stage of its effusion Be, Pb, Cu, Zn, Co, Ni, Zr, Bi, Ga, Te, Cr, V, Ba, Sr and Li were determined; in sublimates from basalts of Iubileiny proryv which was cooling during a year and a half, above listed elements were determined more rarely. In sublimates from Biliukai basalt, which is cooling during ten years Cu, Co, Ni, Bi, Te, Cr, V, Ba and Sr were found, while in sublimates from Tuila basalt, cooling for 17 years only Cu, Cr and V were determined. Temperature of fumaroles in all flows was rather uniform, about 300°.

Concentrations of microelements in lava were dependent on its composition. In basic lavas of Kliuchevsky volcano (basalts) microelements are in smaller concentrations than in more acid lavas of Sheveluch (andesites). In them only V, Cr, Co, Ni, Cu, Ga, Sr, Zr, Mo and Ba were determined. In andesites the listed elements are not in lesser concentrations and additionally Be, Pb, Su, Ag, Zn and Bi have been determined.

Exhalations from basalt were bringing about certain concentrations of metals. In high-temperature sublimates compared with the lava additionally Be, Sc, Zn, As, Ag, Cd, Te, Pb and Bi have been determined.

In exhalations from andesite there was no such concentration. Co, Ag and Bi, which are contained in andesite were not determined at all in its sublimates. Some elements were there in lesser concentrations than in lavas.

The increase in metal concentration in exhalations from basalt as compared to those from andesite are, possibly, determined by a higher temperature of basalt and its lesser viscosity.

Evacuation of metal from basalt of Kliuchevsky volcano during the first high-temperature phase was effected to an equal degree as chlorides and sulphates. While on lava flows quantitatively chlorides were predominants among the sublimates, yet sulphates contained a greater variety of microelements. Compared to chlorides they additionally contained Zn, Zr, Cd and Su. With the exception of copper we did not see any prevalence in the transfer of metal in a chloride form.

Water steam, being the main component of volcanic gases, actively participated in the transport of metals itself and increased the activity of other gases, which did not receive sufficient attention in the study of volcanic processes. At high temperatures superheated water steam (temperature at gas issue was about 500°) evacuated from the lava silicon, which settled on the surfaces of incandescent fractures in explosive craters of Iubileiny proryv as tridymite. Fluorine which could have transported silicon in the form of SiF_4 was not determined in the gases. One can think that silicon was flying in superheated water steam, possibly, like complex molecules with water. In such a tridymite spectroscopically As, Pb, Cu, Ag, Zn, Co, Ni, Mo, Bi, Tl, V, Li and Sc have been determined.

According to our observations metals continued to be extracted from the lava, which already had time to cool, by penetrating gases and quite often it was done with no less intensity than from its incandescent sections. This process is especially actively performed by gases containing hydrogen fluoride.

Transportation of metals in a gas phase was often effected in the form of aerosols. Aerosols were arising during the cooling of gases and while gases went through the rocks. During the cooling of the incandescent cloud of Sheveluch volcano in 1946-1948 volatile haloids and sulphates of metals contained therein were changing over into solid particles, which in the form of aerosols were carried away for 2-3 km from the center of eruption. At a distance they settled in a loose incrustation on cold blocks of lava. Such incrustations consisted of thernadite, aphtitalite, bloedite, polyhalite, glauberite, halite, sylvite and vanadium sulphates.

Aerosols were forming also at temperatures around 100°. Steam was transporting solid particles of mineralforming oxides, liberated in the sulphuric acid decomposition of rocks. Artificial condensates of such vapors, formed on Mendeleyev and Golovnin volcanoes (Kunashir island) contained a higher quantity of cations, as compared to anions. Among the cations the first place belonged to calcium, then came magnesium, silicon, alkaline metals. The condensates were opaque, opalescent and were probably colloid solutions. A highly inadequate quantity of anions (Cl, SO_4, CO_3) for bonds with cations permits to suppose that metal oxides were present in the water steam. In the places of steaming, andesites regenerated into clays deprived of these elements (Ca, Mg, Na, K and partly Si).

In water steam metals were transported also in a dissolved state in the tiniest drops of water, which are present in the steam. Especially favorable conditions for a steam and water mixture are created by the ascent of superheated waters into zones of lesser pressures. Artificial condensates of steams obtained by us in the geyser region of the Valley of geysers are very close in their composition to the water of neighbouring geyser hollows. They are sulphate-chloride-carbonated and impregnated by the same metals and in the same ratio as the water.

Consequently numerous observations of fumarolic activity of volcanoes provide evidence of the transportation of metals having been done in a gaseous phase.

However, of foremost importance is the question how intense gaseous transportation of metals is and whether it can lead to sufficient concentrations in the elements of ore deposits can not be decided in such a way. Unfortunately, volcanologists do not possess precise quantitative data on the content of easily volatile components as compared to difficultly fugitive components and even less so on the ratio of metals transported by them as compared to the total volume of lava and gases. We are under the impression that the quantity of metals in exhalations is very insignificant. It is possible to come to this conclusion judging by artificial condensates of volcanic gases. Chlorine, sulphur and carbon monoxide are mainly flying off in combinations with hydrogen and oxygen and not with metals.

When the liquid phase of water appears, the process of postvolcanic change of rocks and migration of elements considerably intensifies. At temperatures below the critical water temperature volcanic vapors condense and volcanic HCl, SO_2, H_2S are dissolving in them. At depth this happens also with Co_2. The solutions, which are being formed, interact with the rocks and transfer metals into the solutions.

How intense the transition of metals into solution is, is demonstrated by facts of a deep regeneration of lavas into opalites in solfatara and hydrosolfatara regions, when all their elements with the exception of silica and titanium are transferred into solution.

During the process of cooling of exhalations and as a result of chemical reactions of volcanic gases among themselves, with atmospheric gases and rocks, fumarolic minerals have been formed. Of these on Kamchatka volcanoes the following have been determined: *Elements* -sulphur. *Oxides* - tridymite, opal, chalcedony, tenorite, hematite, magnetite, limonite, sassolite. *Sulphides* - pyrite, marcasite. *Halides* - chlorides, halite, sylvite, sal-ammoniac, chlormagnesite, lawrencite, molysite, chloralluminite, kremersite, erythrosiderite, atacamite, hydromelanothallite. *Fluorides* - fluorite, zamboninite (?), ralstonite, hieratite, malladrite, cryptohalite. *Carbonates* - calcite, aragonite. *Borates* - ferruccite, avogadrite. *Sulphates* - thenardite, metathenardite, aphtitalite, palmerite, anhydrite, glauberite, mirabilite, syngenite, löweite, bloedite, picromerite, ferrinatrite, polyhalite, voltaite, mendozite, kalinite, potash alum, soda alum, basanite, gypsum, chalcanthite, hexahydrite, melanterite, epsomite, roemerite, pickeringite, ferropickeringite, halotrichite, coquimbite, ferroalunogen, alunogen, sulphohalite, alunite, natroalunite, jarosite, natrojarosite, euchlorine, kainite, aluminite, fibroferrite, metavoltine, copiapite.

Owing to quick cooling of gases upon their escape to the surface of the Earth, sublimates are being formed as cryptocrystalline mineral mixtures (submicroscopic mixtures of halite and sylvite, thenardite and aphtitalite, sal-ammoniac and kremersite).

Optical properties of many fumarolic minerals are not constant (especially refringence and birefringence). In case of sublimation solid solutions are being formed and a higher or lower refringence is determined by a dissolved component (KCl in halite, K_2SO_4 in thenardite). Fluctuations in optical properties of incrustation sulphates are determined first of all by changes in water content (at the expense of hydration and dehydration) as well as the presence of isomorphic mixtures (halotrichite-pickeringite, alunogen-ferriferous sulphate).

Sublimates and incrustations reflect to a certain extent the specific features of lava composition. Kamchatka lavas contain more sodium than potassium (an average of $Na : K = 3 : 1$); in sublimates and incrustations sodium also prevails over potassium. In sublimates of a mixture of halite and sylvite the ratio is $Na : K = 3 : 1$); in sublimates and incrustations sodium also prevails over potassium. In sublimates of a mixture of halite and sylvite the ratio is $Na : K = 3 : 1$, in sublimates of a mixture of thenardite and aphtitalite $Na : K = 20.1 : 1$, in mixtures of fluorides and sulphates, as a rule, sodium is predominant over potassium, in mixtures of sulphates and in alums $Na_2 : K = 3 : 1$. Basalts of Kliuchevsky volcano are enriched by copper, in sublimates copper chlorides are often to be found; andesites of Sheveluch are enriched by vanadium and in sublimates vanadium sulphates are often.

During the eruption and a long time afterwards volcanic gases and solutions, formed under lower temperatures, passing through the rocks along fissures and pores, interacted with them and changed them in some direction. The character of the changes to which the rocks were subjected depended both on the composition of the rocks themselves and on the physical condition (gaseous, liquid), temperature, composition, concentration and acidity of solutions.

The change of rocks by gases is generally insignificant and takes place on small areas. It is more intensive if fluorine is present in the gases.

On all lava flows from lateral craters of Kliuchevsky volcano white and cream fields of rocks, regenerated under the influence of gases, containing fluorine into aggregates of fluorine minerals, were sharply distinguishable on the black background of basalt. Basalt was discoloured in some cases preserving his texture but in others becoming transformed into a loose mass of fluorides. Regenerated lava as compared with fresh basalt is poorer in silica and iron oxides. Other rock forming elements are contained in it in approximately the same relative amounts in which they have been in fresh lava.

During the first stage of decomposition the rock preserved its structure, but minerals and the vitreous mass were partly replaced by isotropic fluorine minerals. In the first instance the vitreous ground mass of the rock was subjected to replacement, getting discoloured near the pores in spots; plagioclase was replaced by fluorides before other minerals and the replacement began in separate zones of zonal phenocrysts. Replacement of pyroxene proceeded along cracks. During the second stage of decomposition the rock was losing its original structure and density and was disintegrating into an aggregate consisting of isotropic fluorine minerals with a refringence from 1,330 to 1,400.

The change of rocks under the influence of fluorine (gaseous fluormetasomatism) has no wide development and is limited to small patches in craters and on lava streams.

In the region of solfataras and hydrosolfataras the strongest changes of the rocks take place under lower temperatures, providing the appearance of water solutions at the expense of volcanic steam condensation and atmospheric humidity.

On solfatara fields of Sheveluch, where emanating gases are characterized by a considerable concentration of hydrogen sulphide and sulphurous gas, they are subjected to violent oxidation, formation of sulphuric acid and, consequently, of more acid and concentrated solutions. Lava (andesite) in the region of solfataras is fully decomposed and regenerated into white compact and loose masses, enriched by opals.

Chemical decomposition of the rock consisted in a gradual transfer into solution of all components, except silica.

The regenerated rock, as compared to the fresh one is much poorer in oxides of aluminium, iron, calcium, magnesium, sodium. The end type of lava and tuffs changes by acid solutions in the regions of solfataras is the formation of a gel by silicic acid. Hot, jelly-like silicic acid gel, containing up to 52 % of water, is mobile and fills the fissures forming veinlets. In future in the jelly-like gel a process of silicic acid condensation into a more complicated by its structure skeleton of a chalk-like silicagel is taking place. This silicagel consists of an intertwining of fibers, forming a mass of pores filled by water. When the silicagel is dehydrated an opal containing 4-7 % of water is being formed which by ageing changes into quartz.

Opalization in the region of solfataras on volcanoes has an areal character and wide development. It is possible that the formation of secondary quartzites of some deposits takes place in such a way.

On solfataras with a weak concentration of hydrogen sulphide and sulphurous gas argillitization took place when less acid sulphurous solutions were formed. Lavas along the routes of steam and sulphurous gases penetration were decomposed and were transformed into coloured clays.

Among clays not fully decomposed blocks of lava can be found quite often, on which all the stages of a sulphuric acid decomposition can be traced, beginning with bleached compact rocks with a porphyritic texture with completely caolinized plagioclases of phenocrysts and up to amorphous clays.

A petrographic change of andesites finds its expression, first of all in a decomposition of feldspars in phenocrysts, often selectively in separate zones and primarily of those which are rich in anorthite and then the others. Plagioclase in transmitted light becomes turbid, it is replaced by kaolinite. Coloured components are replaced after plagioclase (first amphibole, then pyroxene) by a greenish, fibrous, poorly birefringent chlorite. Oxides of iron appear in the fissures of the rock. During this stage of decomposition the rock preserves its density and original structure. Later the rock, keeping its porphyritic structure, becomes soft and crumpling under pressure. Phenocrysts of plagioclase are fully replaced by kaolinite and in the groundmass many iron oxides appear. During the next stage of decomposition the rock gets loose, structureless, bleached and fully consisting of clayey minerals. Among those kaolinite is predominant. Admixtures to kaolinite consist of hydroxides of iron, opal, gypsum and sulphur.

In the process of argillitization concentration of aluminium (and iron) takes place mainly at the expense of evacuation of other elements as well as at the expense of precipitation from solutions when their acidity diminishes (increase of pH). This process took place under the influence of a thinning of solutions and their neutralization caused by a continuing intercalation of solutions and rocks. In clay deposits of solfataras on Koshelev volcano, formed by precipitation from solutions, concentrations of aluminium and iron were higher than in clays formed by leaching. Fluctuations in the content of aluminium and iron in clays depend upon the acidity of solutions acting on them. Under an acidity of and somewhat above 5, red ferruginous clays were formed; under an acidity of solution below 5 iron changes over into a solution and white clays enriched by aluminium were formed.

In the region of some solfataras and hydrosolfataras on Kikhpinych and Koshelev volcanoes the formation of alunites was taking place. Contrary to opalization and argillitization alkaline metals were not carried out by solutions, but were bound into a basic sulphite salt - alunite. During this process the regenerated rock was enriched by potassium.

In the district of Verkhnegeyserny hydrosolfataras at the foot of Kikhpinych volcano alunitization is taking place at the present time as well. The waters of hydrosolfataras are acid (pH about 5), sulphate-ammonium-calcium-magnesium. Here, better than in any other place, one can obviously see the formation of the mineral composition of hydrosolfatara waters at the expense of evacuation from the rocks by sulphate waters of calcium and magnesium and the enrichment through this regeneration of the rocks by sodium, potassium and aluminium.

From a comparison of chemical compositions of andesite-dacite and the rock formed at its expense one can see that during alunitization the rocks get poorer in silica, iron, calcium and magnesium and richer in aluminium, alkaline metals (at the expense of potassium), sulphurous anhydrite and water. Altered rocks have in their composition up to 87 % of alunite.

On Kikhpinych alunitization is accompanied by an impregnation of sulphides. Kamchatka alunites are sodic though in alunitized rocks with an increased amount of alkaline metals as compared with the fresh rock - andesite-dacite - there is more potassium than sodium. While in the lava the ratio is $Na_2O : K_2O = 3 : 1$, in an alunitized rock $Na_2O : K_2O$ is close to 1 : 1.

In the region of alkaline thermal springs (Kirsunskie), in the places of steaming, clays are being formed of a montmorillonite-beidellite composition. Contrary to the sulphurous effect, the rock changes chemically only slightly, but mineralogically it changed completely. Instead of labradorite, augite and glass, montmorillonite and beidellite were formed.

The process of opalization and argillitization is accompanied by the formation in the subsurface (sharply oxidizing) zone of sulphur and sulphates. Metals for the formation of the latter (rock forming and dispersed) are extracted out of rocks during their sulphurous decomposition. Sulphates are crystallized on the surface of thermal areas owing to an increase in the concentration of solutions at a loss of the solvent (evaporation of water) and on their cooling. They temporarily enter into paragenesis with other minerals, but, owing to a good solubility, with the exception of gypsum, basanite, anhydrite and alunite are not fixed in geological formations. On the solfataras of Mendeleyev volcano (Kunashir island) by workings and erosion deeper horizons of altered rocks enriched by sulphides of iron have been uncovered. The precipitation of sulphides took place at an encounter of ascending solfataric solutions rich in H_2S or a sulphide ion with descending solutions rich in sulphate iron at the expense of superficial sulphurous decomposition of rocks.

At the expense of dissolution and concentration of volcanic exhalations in meteoric waters thermal waters of a specific composition are created. The character and degree of effect volcanic exhalations have on the composition of mineral springs depend upon the conditions of the exhaling magma - whether it exhales haloid, sulphurous and carbonic gases or only sulphurous and carbonic; on the depth of the place on which the condensation and dissolution in infiltration waters of volcanic exhalations takes place and finally on the temperature regime. These conditions determine the vertical and horizontal zonality of waters.

The initial moment in the formation of thermal waters is the dissolution of volcanic gases (H_2O, HCl, SO_2, H_2S etc) in infiltration waters. This has been traced by us in the points of gas emergence in lower sections of relief, which provides for an accumulation of superficial and ground waters.

Superheated waters, enriched by ions of chlorine, sulphate and hydrocarbonate at the expense of volcanic gases dissolution, actively interact with contact rocks and transfer into solutions rockforming and microelements. In such a way in the region of active volcanoes sources of the mineral composition of thermal waters are partly volcanic exhalations (Cl^-, SO^{2-}_4, HCO^-_3, NH^+_4, F, B, As and possibly some metals) and partly rocks contacted by the water (main mass of metals).

The cation composition of the waters is in direct dependence upon the acidity of the water, its temperature and concentration of chlorine, sulphate and hydrocarbonate ions.

Silica is always present in the waters of Kamchatka and Kurile thermal springs.

The richest in silica are the most acid and most alkaline waters. In waters with an acidity of 2-7 there are minimal amounts of silica. Under pH 2 - H_2SiO_3 an average of 336 mgm/1 (max. 415 mgm/1); under pH 2-3.5 H_2SiO_3 an average of 170 mgm/1; under pH 5.6-7.6 - H_2SiO_3 an average of 120 mgm/1; under pH 8 H_2SiO_3 an average of 300 mgm/1 (max. 380 mgm/1).

Generally speaking for thermal waters of Kamchatka 500 mgm/1 of H_2SiO_3 is a limite value.

The content in waters of aluminium and iron is in direct dependence upon the acidity of the water. In waters with pH 4 there is no iron nor a aluminium. Calcium and magnesium are present in the water always and their amounts often do not depend upon the temperature, acidity or composition of the water. Practically in all Kamchatka waters calcium is predominant over magnesium, however, the ratios Ca: Mg vary in different waters. In acid sulphate waters of a superficial origin Ca : Mg = 3-8 : 1 oftener 3 : 1 reflecting their content in volcanic rocks. In alkaline sodium-chloride and chloride-sulphate waters 20-40 : 1, in carbonated waters 0.2-3 : 1. Only in carbonated thermal springs magnesium sometimes predominates over calcium, possibly at the expense of the selective precipitation of calcium as a carbonate as compared to magnesium.

Sodium and potassium are present practically in all waters. In acid sulphate waters sodium and potassium are present in insignificant amounts often in the same proportions as in the rock, thus reflecting the conditions under which the water was formed. Under a sulphurous influence upon the rocks alkaline metals often get into the basic sulphite salt of alunite and jarosite; correspondingly there is little alkaline metals in the waters. An especially excessive amount of sodium as compared to potassium, just as in other volcanic regions, is observed in alkaline sodium-chloride waters, which is generally typical for alkaline thermal springs.

Waters of thermal springs in regions of active volcanoes on Kamchatka and the Kurile islands contain a number of microelements, but, with the exception of arsenic and boron, we did not discover any special concentration of them in waters as compared to rocks. In Kamchatka waters the following elements have been determined: Sb, Pb, Sn, Cu, Ni, Zn, Mo, Ga, Li, Ba, Sr, Bi; in Kuriles waters: Pb, V, Cu, Zn, Zr, Cr and Sr.

Owing to a change in external pressure, temperature and medium, mineral precipitates are dropping out of the waters of thermal springs upon their emergence on the surface. The composition of the precipitates only partly reflects the composition of the waters inasmuch as not all the components form insoluble products of reaction. Under a change in pressure and as a result of evacuation from the waters of Co_2, precipitation of calcium carbonate, hydrates of iron and aluminium and oxides of silica is taking place (Nizhne-Koshelevsky volcano).

Out of the waters of Kislaia Rechka on Kunashir Island, as a result of a change in the acidity of the water, effected by its dilution by fresh waters, hydrates of Al and Fe oxides are precipitated absorbing a whole number of microelements (As and oth.). At the oxidation of waters rich in ferrous sulphates at Nizhnekoshelevskie springs yarosites were precipitated. Under a change in the concentration of waters owing to evaporation from them of superheated geyser waters oxides of silica (geyserites) were precipitated. From colloidal solutions of the crater lake on Golovnin volcano sulphur and silic acid were precipitated as a result of coagulation. Hydrated precipitates and precipitates from colloidal solutions partly concentrated microelements As, Mo, Zn, Co, V, Pb, Cd, Ga, Be, Cr.

Observations of manifestations of present-day volcanism were always of tremendous importance in formulating ideas on magmatic processes and on the origin of ore deposits. That is why additional studies of the composition of volcanic exhalations are always of great interest.

Academy of sciences of the USSR
THE NATIONAL COMMITTEE FOR GEODESY
AND GEOPHYSICS
Section of volcanology

V. V. IVANOV

Present-day hydrothermal activity within the Kurile-Kamchatka Island arc and its relation to volcanicity

Introduction

Kamchatka and the Kurile islands being the most northern link of the largest system of island arcs in the Pacific, form a region where latest volcanism is intensely developed and which is characterized by a very varied hydrothermal activity. The type and origin of steam - and hydrothermae of the Kurile-Kamchatka volcanic zone are in many respects fundamentally different from the character and origin of hydrothermae, forming within the vast continental part of Soviet Far East and the Sakhalin island.

All the Kurile Islands and the volcanic regions of Kamchatka are part of an extensive and peculiar Pacific province of thermal springs and gas-steam jets, an area of latest volcanicity which extends further to the South-West into the Japanese islands (Hokkaido, Honshiu, etc.) and to the Aleutian islands in the East.

Numerous researches carried out in the Soviet Union during the last decades (B. I. Piip, V. I. Vlodavetz, V. V. Ivanov, T. I. Ustinova, S. I. Naboko, O. N. Tolstikhin and others) on the geological conditions of emission and composition of volcanic gases and thermal waters of this zone, permit to have a definite judgement regarding their origin and the laws governing their distribution. It became also possible to compare them with reknown hydrothermae of

Iceland, Japan, New Zealand and other regions of present-day volcanism.

The most important factors determining the character of present-day hydrothermal activity on Kamchatka and the Kurile islands are: a lengthy and intense past (Tertiary and Quaternary) volcanic activity, cases of present-day active volcanism and an abyssal thermometamorphism of rocks, a wide development of latest tectonic fractures and an abnormally high - « volcanogene » - geothermic regime.

However, by far not all hydrothermae on Kamchatka and the Kuriles islands, just as in other regions of latest volcanism, are being formed as a result of a direct influence of present-day volcanic processes. A considerable part of them acquires the character of recent hydrothermae only owing to abnormally high geothermic conditions which are predominant within the depths of volcanic regions and are not genetically associated with magmatic and thermometamorphic exhalations rising from the depth.

The chemical composition and genesis of hydrothermae is determined first of all by geological and geochemical conditions under which they are being formed in the rocks, while the form of their existence in the depth and the manner in which they appear on the surface are mainly controlled by thermodynamic conditions prevailing within the entrails of volcanic regions. Depending upon the conditions of pressure and temperature the same hydrothermae can occur in the depth in a liquid or vaporous state and can appear on the surface in quite different forms.

As in other regions of latest volcanicity, present-day hydrothermal activity within the Kurile-Kamchatka volcanic zone is manifest in three main forms: exhalations of hot volcanic gases, discharge of thermal waters different in their genesis and composition and emission of steam jets. Their brief characteristic is given in table No 1.

Main forms of present hydrothermal activity on Kamchatka and the Kurile Islands.

	Main forms of activity	Main types	T in °C	Main components of the		Conditions of formation
				Gas composition	Ionic-salt composition	
I.	*Exhalations of volcanic / fumarolic gases*	1. High-temperature (chlorous-sulphurous-carbonated)	hundreds of degrees	HCl, HF, CO, CO_2, H_2S, SO_2, H_2, NH_3, CH_4, $(N_2 \div O_2)$	—	Under magmatic and thermometamorphic conditions
		2. Low-temperature (hydrogen sulphide-carbonated)	up to 100 or somewhat higher	Co_2, H_2S, sometimes CH_4	—	Under magmatic and thermometamorphic conditions
II.	*Discharge of thermal waters*	1. Sulphurous-carbonated	80-100	Co_2, H_2S, sometimes CH_4	SO_4, Cl, H, Fe, Al, NH_4, HCl, H_2SO_4, H_2SiO_3, HBO_2	Under conditions of oxidation, in a sphere of volcanic gases influence
		2. Carbonated	30-75	CO_2	HCO_3, Cl, SO_4, Na, Ca, H_2SiO_3	Under reducing conditions, in a zone of influence of thermometamorphic processes
		3. Nitric	50-100	N_2	Cl, SO_4, Na, H_2SiO_3	Under reducing conditions, out of genetic relations with magmatic and thermometamorphic exhalations
III.	*Emission of steam jets*	1. Abyssal	about 100	traces of CO_2, N_2	—	As a result of a transition into vapour (underground « boiling ») of abyssal superheated pressure waters
		2. Surficial	100	$N_2 \div O_2$	—	As a result of a transition into vapour in heated rocks of descending cold waters

1. Volcanic gases

Exhalations of volcanic fumarole gases on Kamchatka and the Kurile Islands are genetically and spatially associated with foci of active volcanism and are mainly, just as in other similar regions, gases of magmatic and thermometamorphic origin. They consist of very different components: HCl, HF, HH_2, H_2S, SO_2, CO, CO_2, CH_4, NH_3, B and certain others. Their temperature at the orifice varies usually very widely - from 100 up to 500-600 and more degrees C.

Among these gases there are two main, characteristic types, specific features of which are to a great extent determined by thermodynamic conditions of their exit to the surface:

1. High-temperature (hundreds of degrees) **volcanic gases** of a complex composition (chlorous-sulphurous-carbonated) emitted in craters of volcanoes during short periods of eruptions as well as during lengthy periods of intense fumarolic activity.

These gases migrating from magmatic hearths to the surface under geothermic conditions excluding their encounter with water in a liquid state, contain usually at the moment of emission H_2, HCl, SO_2, CO, CO_2 as their main components, N_2 in predominant quantities as well as some other gases (including always fumes of H_2O).

Big quantities of nitrogen, discovered by analyses in samples of these gases, are regarded by the majority of researchers as a result of suction in of atmospheric air along cracks and pores of rocks (above the ground water level) towards the greatly heated volcanic gases. The oxygen contained in this air is fully or mostly spent on various oxidizing processes with the formation of a number of new compounds and first of all of the group S and C.

Tremendous quantities of water steam which are present in these gases (up to 90-99 % of the total volume of gases) are, apparently, of a non-magmatic origin mostly, but are formed at the expense of steam, exhaled during the thermometamorphism of rocks, as well as a result of transition into steam of usual underground water, which in its infiltration reached high temperature volcanic vents.

To this type of gases belong on Kamchatka crater gases of active volcanoes of Kliuchevskaia sopka, Sheveluch, Avacha, etc. and gases of many volcanoes of the Kurile islands, the composition of which, however, is not sufficiently studied yet. New analyses of volcanic gases of Kliuchevskaia sopka and Sheveluch show that some of them contain (after deduction of water and air steam): up to 13.2 % of HCl, up to 6.4 % of H_2, up to 7.7 % of SO_2, up to 7.5 % of CO, up to 16.7 % of CO_2 and sometimes also F and NH_3.

2. **Relatively low-temperature** (up to 100°C or somewhat higher) **fumarolic gases of a simpler chemical composition** (hydrogen sulphide-carbonated) emitted to the surface from less heated sections of the rocks on the flanks of volcanoes and in large calderas.

Before reaching the surface these gases get into thermodynamic conditions where water is in a liquid phase so that they get sort of filtered through underground waters giving away to them all easily soluble components like Cl, F, SO_2, NH_3 and many others.

That is why only CO_2, H_2S (sometimes up to 48 %) and CH_4 (sometimes up to 24 %) are preserved in these gases. Very characteristic is a virtually complete absence of nitrogen. Emission of these gases is usually associated with fumarolic thermal springs and is very widely developed both in the region of present-day volcanism on Kamchatka (volcanoes Centralny Semiachik, Uzon, Koshelev, Kambalny and many others) and on the Kurile islands (Ivan Grozny, Mendeleyev volcanoes, etc.).

In such a way the above mentioned division of volcanic gases into two main big groups is determined fundamentally by the thermodynamic conditions of their existence in the depths of rocks - their interaction with underground waters, which, of course, does not exclude changes in their character and composition caused by a change in the condition of the volcanic hearths in the depths of the earth.

II. Thermal waters

All thermal waters of Kamchatka and Kurile islands which flow out to the surface as various thermal springs, are divided by their gas content, which reflects with the highest precision the geochemical conditions of the origin of these waters in the depth, into three main genetic types: sulphurous-carbonated (fumarolic), carbonated and nitric (alkaline) thermae (table No 1).

These three types of thermae are quite distinct also in many other regions of present-day volcanism (Japan, Iceland, New Zealand, etc.).

Sulphurous-carbonated thermae. Fumarolic and always very acid thermal waters are being formed only in regions of present-day volcanism, in a medium which is under a direct influence of active volcanic hearths in the upper oxidizing zone of the youngest volcanic rocks. The formation of these waters proceeds through the saturation of underground waters and, under favorable conditions of relief, also of surface waters with above characterized volcanic gases. This saturation takes place on the flanks, in calderas and craters of volcanoes. Their temperature is usually high and comes to 95-100°C.

According to the above stated theory of interaction between volcanic gases and underground waters, fumarolic thermae are subdivided into two subtypes - waters of « abyssal » and waters of « surface » formation.

The former have a chloride-sulphate composition and are formed by the saturation of underground waters by volcanic gases containing HCl, H_2S, CO_2 and some other components. The latter are characterized by a purely sulphate composition and originate as a result of saturation of ground and surface waters by hydrogen sulphide-carbonated gases already filtered at depth by underground waters.

The chemical composition of these thermae possesses a number of specific features: a sharply-acid reaction, determined by the presence of a free sulphuric acid and sometimes even hydrochloric acid, usually not a high general mineralization (with rare exceptions less than 5 gm. p. litre), the presence in their composition of H, Fe and Al cations, and in the thermae of Kamchatka sometimes big quantities of ion NH_4.

High content in these waters of a free sulphuric acid and sulphates in general is the result of oxidation of sulphurous gases penetrating into the waters (H_2S, SO_2, SO_3, SO_4). Considerable concentrations in them of Fe and Al are determined by the influence of sulphurous solutions on rocks.

All fumarolic thermae are present-day waters in the full meaning of this word and have a limited focal development only in the sections where volcanic gases are emitted. Their regime is very unstable. They are distributed very widely all through the Kurile islands and in the eastern volcanic zone of Kamchatka.

A brief chemical characteristic of some typical representatives of these thermae on Kamchatka and the Kurile islands is given in table No 2.

TABLE No 2.

Brief chemical characteristic of some fumarolic thermae on Kamchatka and the Kurile Islands

	Name of spring	To in C°	Mineral. in gm. p. litre	Formula of ionic composition (in mg./eq./%)	pH	H_2SiO_3 in gm. p. litre
				Waters of a « surface » origin		
	Kamchatka					
1.	Verkhne - Koshelevsky	98.0	1.1	$\frac{SO^4_{95}}{NH^4_{30}H_{27}}$	2.6	0.819
	Iturup Island					
2.	Sernozavodsky	43.0	2.7	$\frac{(SO^4 \div HSO^4)_{97}}{Al_{49}Ca_{25}H_{23}}$	2.2	0.153
	Kunashir Island					
3.	Golovninsky	96.0	6.7	$\frac{(SO^4 \div HSO^4)_{95}}{H_{40}Al_{34}Fe_{10}}$	1.5	0.384
				Waters of « abyssal » origin		
	Paramushir Island					
4.	Verkhne - Yurievsky	95.0	17.6	$\frac{SO^4_{57}Cl_{43}}{H_{44}Al_{21}}$	0.86	0.317
	Kunashir Island					
5.	Nizhne - Mendeleyevsky	91.3	4.3	$\frac{(SO^4 \div HSO^4)_{55}Cl_{45}}{H_{33}Al_{17}Fe_{16}Ca_{12}(Na \div K)_{13}}$	1.7	0.315

Carbonated thermae. These thermae make a very characteristic group of thermal waters, substantially different by their genesis, composition and distribution from the above described fumarolic springs. Their origin is associated not only with present-day but also with older (Early-Quaternary and Late-Tertiary) magmatic processes, which create at a certain depth an intense thermometamorphism of rocks and an exhalation from them of CO_2.

On Kamchatka carbonated springs are developed very widely (mainly within the East-Kamchatka region of present-day volcanicity), while on the Kurile Islands, on the contrary, they occur very rarely.

As in other regions, the formation of carbonated waters on Kamchatka proceeds, as a rule, in closed and semiclosed geological structures, characterized by a hindered water exchange and mostly in deep-seated Mesozoic rocks or, to a lesser degree, in Tertiary deposits under a mantle of Quaternary volcanogene rocks.

Under favorable geostructural conditions they can form at depths large artesian basins or complicated systems of fissure pressure waters.

The temperature of carbonated thermae at the place of issue to the surface does not exceed 75°C and their flow is usually not high. In the gas composition of these springs CO_2 occupies a predominant position (up to 90-95 %); sulphuretted hydrogen as well as methane is absent, with maybe rare exceptions.

By its ionic composition carbonated springs are characterized among anions by a usually high content of HCO_3 and in some waters of Cl as well. Among cations there is usually a marked predominance of Na. Total mineralization of these waters does not exceed 7.5 g/1 (table No. 3).

Table No 3.

Brief chemical characteristics of some carbonated thermae of Kamchatka and the Kurile Islands

	Name of spring	T in oC	Mineraliz. in g/1	Formula of ionic composition (in mgm./eq./5)	pH	H_2SiO_3 in g/1
	Kamchatka					
1.	Nalachevskie	74.8	4.4	$\frac{Cl_{72}}{(Na \div K)_{75}Ca_{21}}$	6.4	0.191
2.	Timonovskie	48.0	3.2	$\frac{HCO^3{}_{44}Cl_{34}SO'{}_{22}}{(Na \div K)_{66}Ca_{20}}$	6.5	0.217
	Iturup Island					
3.	Dachny	34.0	5.9	$\frac{Cl_{60} \cdot HCO^3{}_{38}}{Na \div K)_{70}}$	6.0	0.174

The main processes which determine the ionic composition of carbonated springs are leaching processes of rocks by infiltration waters rich in CO_2; it is possible also, that a certain part in their composition belongs to residues of strongly altered marine waters of sedimentary deposits.

The above said shows that there is ground to suggest, as it is done by many researchers, that all carbonated thermae in regions of present-day volcanism are formed as a result of metamorphosis (within rocks) of acid fumarolic thermae.

Nitric thermae. Nitric thermae on Kamchatka have a wide development, but on the Kurile Islands until now only several springs of this type are known.

All typical representatives of such waters are characterized by a very high temperature, possess a small mineralization and a distinctly alkaline reaction (pH up to 9.3). They are subdivided into two characteristic groups.

The first group - of chloride-sulphate sodium, more seldom calcium-sodium waters with low total mineralization (up to 1.5 g/1), with a very high ratio Cl/Br (an average over 1000), with a typically aerial ratio Ar to N_2 - is represented on Kamchatka by numerous springs (Paratunskie, Nachikinskie, Bannye, Malkinskie, Apapelskie and many others).

Their usual temperature is 70-100°C, the yield as a rule does not exceed 10 litres per second.

These waters are genetically associated mainly with volcanogene or volcanogene-schistose masses of rocks of a varying composition and age (from Mesozoic to Quaternary) and are typical fissure infiltration waters of leaching, of an atmospheric origin, circulating in deep zones of tectonic crushing.

Their very high temperature is fully determined by abnormally high geothermic conditions of their circulation.

The second group of alkaline springs is represented within the Kurile-Kamchatka arc by a few very powerful and interesting groups of springs: on Kamchatka - Geysers, Pauzhetskie and Kireunskie springs; on the Kurile Islands - springs of the Goriachi Pliazh (Kunashir Island). These waters are distinguished by a higher mineralization (2.0-4.6 g/1), an identic chloride-sodium composition, usually by an insignificant content of ion SO_4, an increased content of boron and a lower ratio Cl/Br (in the range of 300-700). (Table No. 4). Gases in these waters are represented by nitrogen with insignificant mixtures of CO_2 and sometimes of CH_4.

All the listed groups of springs are fed by strongly superheated (probably up to 150-200°, and maybe even higher) high pressure waters. All of them are intensely boiling and strongly vaporizing springs with a temperature about 100°C, possess usually a very high yield (over 25 litres per second) and are characterized sometimes by a geyser regime of gushing.

The formation of these waters is associated both on Kamchatka and on the Kurile Islands with deeply occurring horizons of marine sedimentary and volcanogene-sedimentary Tertiary rocks, exposed only on rare occasions by deep tectonic fractures.

The origin of these waters under conditions of very high temperatures and great pressures determines their being rather rich in silicon dioxide (up to 250-330 mgm/1) and leads to a deposition in the areas of their issue of characteristic siliceous encrustations-geyserites.

A complete analogue of such waters are chloride highly thermal waters discovered recently in New Zealand during drillings for power projects (S. H. Wilson, 1955). To this type of springs belong, apparently, also strongly superheated waters uncovered by deep boring for power utilization in Italy and Japan.

Leaving aside the complicated and not quite clear question regarding the origin of Cl in these waters, which, depending upon the geological and hydrogeological conditions can be, possibly, of both a volcanic and marine origin, we think it necessary to stress that the characteristic chloride-sodium composition (often nearly sulphateless) of the described springs is determined, apparently, by a specific geochemical medium of their formation in depth, namely sharply-reducing conditions of high temperatures dominating in deep interiors of active volcanism under which SO_4 ion proves to be unstable, as thinks A. G. Betekhtin (1933) and « subject to decay with elimination of oxygen ».

There are reasons to suggest that in great depths and under mentioned geological conditions this type of springs is especially widely developed, forming large artesian basins or systems of fissure pressure waters which represent powerful hydrothermal resources of great importance for power purposes.

III. Steam jets

Issues of steam jets, sometimes with insignificant mixtures of certain gases (CO_2, H_2S, N_2 and others) are registered only in active volcanic regions of Kamchatka and Kurile Islands, characterized by a highly thermal regime. In all cases the emergence of steam to the surface should be regarded as a result of a transition of strongly heated underground waters into a vaporous state.

Table No 4.

Brief chemical characteristics of some nitric thermae of Kamchatka, the Kurile Islands and New Zealand.

	Name of spring	T in oC	Mineraliz. in g/1	Formula of ionic composition (in mgm./eq./%)	pH	H_2SiO_3 in g/1
				Chloride-sulphate waters		
	Kamchatka					
1.	Nachikinskie	80.6	1.2	$\frac{SO^{4}{}_{59}Cl_{34}}{(Na \div K)_{90}}$	8.4	0.109
2.	Bolshie Bannye	97.0	1.2	$\frac{SO^{4}{}_{68} \cdot Cl_{21}}{Na \div K)_{92}}$	8.6	0.156
	Kunashir Island					
3.	Dobryi Kliuch	68.2	1.4	$\frac{Cl_{63}SO^{4}{}_{34}}{(Na \div K)_{72}Ca_{23}}$	8.0	0.736
				Chloride waters		
	Kamchatka					
1.	Geysernye	98.9	2.2	$\frac{Cl_{83}}{(Na \div K)_{94}}$	8.7	0.330
2.	Pauzhetskie	100.0	3.2	$\frac{Cl_{93}}{(Na \div K)_{88}}$	8.2	0.249
	Kunashir Island					
3.	Goriachi Pliazh	100.0	4.6	$\frac{Cl_{96}}{(Na \div K)_{93}}$	8.1	0.309
	New Zealand					
4.	Wairakei district Boring No 4	—	3.9	$\frac{Cl_{97}}{(Na \div K)_{95}}$	8.6	0.502

Data of deep borings in active volcanic regions of Italy, New Zealand and other territories show that thermodynamic conditions in great depths make even highly superheated waters (200-300°C) remain there in a liquid state and only in a rapid ascent to the surface with sharply decreased pressures, will these waters convert into a vaporous state.

In some cases this brings about the formation of powerful steam jets, in others, the appearance of constantly boiling and vaporizing springs and, finally, in third cases, under an interaction of highly superheated abyssal waters and underground waters of a lower temperature - to the creation of an effective geyser regime of spouting springs.

All three above described cases can be distinctly observed in present-day hydrothermal activity of the Geyser Valley, discovered by T. M. USTINOVA in 1941 within the Eastern-Kamchatka volcanic zone. There are over 20 big geysers in the valley, many different constantly boiling springs and issues of steam jets.

Contrary to many foreign researchers of geysers, we think that the mechanism of their operation is not determined by an influx of steam « from magmatic hearths », but by a transition into a vaporous state of highly superheated pressure waters which are subject to the usual hydrogeological laws of circulation.

In addition to above listed cases, when often powerful steam jets under pressure are formed, when cold surface waters get into strongly heated subsurface horizons of rocks, there can also be numerous but very insignificant by their volume exhalations of steam.

IV. Main laws governing the distribution of hydrothermae

In the spatial distribution of hydrothermae of the Kurile-Kamchatka volcanic zone there is, just as in other areas of present-day volcanicity, a definite horizontal and vertical zoning, determined first of all, by the intensity of volcanic processes, geothermal conditions, degree of hydrogeological openness of structures (particularly by the presence of young tectonic rifts and fractures), as well as by the character of geochemical conditions existing in the interior of the earth.

Within the territory under discussion there is a number of areas and regions substantially differing in character and scale of their hydrothermal activity. The largest and most important of these areas are:

1. The Kurile area of present-day active volcanicity - characterized by a most intense hydrothermal activity, a presence of numerous points of issue of volcanic gases, steam and thermal waters, mainly fumarolic.

2. Eastern-Kamchatka region of present-day volcanicity - also characterized by a very intense and varied hydrothermal activity. However, unlike the Kurile Islands, fumarolic thermae are represented here only by waters of a « surficial» formation, while carbonated and nitric thermae have a very wide development. Within the region there are sections differing in the composition and origin of thermal waters.

3. Central-Kamchatka region of Early - Quaternary volcanicity - region of a predominant development of nitric alkaline and, on rare occasions, of carbonated thermal waters.

The character of vertical hydrochemical zonality in the region of active volcanoes is closely associated with specific features of their fumarolic activity and possesses, as mentioned above, certain very peculiar traits: the presence in the upper zone of oxidation of strongly acid sulphate waters, somewhat lower chloride-sulphate thermal waters and, under abyssal high temperature conditions, of reduction - everywhere purely chloride, highly overheated waters.

Conclusion

The above stated characteristic of present-day hydrothermal activity of the Kurile-Kamchatka volcanic zone, permits to draw the following conclusions:

1. As is demonstrated by the latest hydrogeological and

hydrochemical studies, all the described hydrothermae are formed mainly at the expense of infiltration waters of an atmospheric origin. Only in thermal waters of deep-seated sedimentary deposits there is probably a certain participation of the remains of old and altered sea-waters (judging by the content of Cl, in any case not over 10-15 %); fumarolic thermal waters of an « abyssal » origin include apparently insignificant quantities of water, formed from the condensation of volcanic gases.

There is no basis to suggest, in the light of present data, that hydrothermal waters of active volcanic regions are « juvenile » flows, emerging on the surface directly from magmatic hearths.

2. Many carbonated and especially abyssal sulphurous-carbonated hydrothermae of the Kurile Islands and Kamchatka, alike analogous springs of other regions of latest volcanicity, should be regarded as present metalliferous hydrothermal solutions, providing transport and, under changing geochemical and thermodynamic conditions, deposition of different metals - Fe, Al, As, Mn, Cu etc.

Physical and chemical features of composition and conditions of origin of metalliferous solutions of the two above mentioned types are different in many respects, as has been demonstrated before. High acidity (very low values of pH) of fumarolic thermae determines the possibility of higher metal concentrations in them. On the other hand, their expansion and duration are smaller (on geological scales of time) than that of carbonated hydrothermae. However, as the study of Kurile thermal springs has shown, abyssal fumarolic thermal waters, under favorable conditions, provide a very intense migration and a considerable delivery of metals to the surface.

A further detailed study of the composition and conditions of formation of thermal springs in regions of present-day volcanicity is of indisputable interest for the determination of interrelations between the processes of present volcanism, thermometamorphism and ore deposition.

3. Study of hydrothermae is also of great pratical value for their utilization as powerful sources of thermal power (for heating purposes and generation of electrical power) and for medicinal purposes.

BIBLIOGRAPHY

1. - Betekhtin, A. G. - *Hydrothermal solutions, their nature and processes of ore formation.* Symposium « Fundamental problems in the theory of magmatogene ore deposits », Moscow, 1953. (In Russian).
2. - Vernadsky, V. I. - *On the classification of natural gases.* Leningrad, 1953. (In Russian).
3. - Vlodavetz, V. I. - *On steam-hydrosolfathermal deposits in volcanic regions of Italy.* Izvestia USSR Acad. of Sci., Geol. ser., No 5, 1955. (In Russian).
4. - Sonder, R. A. - *On the theory and classification of solfathermal phenomena.* Summary of reports to the 17th Session of the Intern. Geol. Congress, Moscow, 1937. (In Russian).
5. - Ivanov, V. V. - *Hydrothermae in foci of present-day volcanicity on Kamchatka and the Kurile Islands.* Proceed. of the Volcanol. Laborat., fasc. 12, 1956. (In Russian).
6. - Ivanov, V. V. - *Steam-hydrothermae of the Kurile-Kamchatka volcanic zone and their importance for power.* Summary of reports to the First All-Union Conference on geothermal researches in USSR, Moscow, 1956. (In Russian).
7. - Ivanov, V. V. - *On the origin of Kamchatka mineral waters.* Symposium « Questions on the study of resort resources in USSR », Moscow, 1955. (In Russian).
8. - Ivanov, V. V. - *Present-day hydrothermal activity of Ebeko volcano on Paramushir island.* Geochemistry, No 1, 1957. (In Russian).
9. - Makarenko, F. A. and Ivanov, V. V. - *Fundamental laws governing the distribution and formation of thermal waters on the territory of USSR.* Summary of reports to the First All-Union Conference on geothermal researches in USSR. Moscow, 1956. (In Russian).
10. - Ovchinnikov, A. M. - *To the question of « juvenile waters ».* Symposium « Questions of petrography and mineralogy », vol. 1. Moscow, 1953. (In Russian).
11. - Ovchinnikov, A. M. - *Laws governing the distribution and formation of carbonated hydrothermae.* Summary of reports to the First All-Union Conference of geothermal researches in USSR, Moscow, 1956. (In Russian).

12. - Piip, B. I. - *Thermal springs of Kamchatka.* SOPS, Kamchatka ser., Moscow, 1937. (In Russian).

12. - Ustinova, T. I. - *Kamchatka geysers.* Moscow, 1955. (In Russian).

14. - Allen, E. T. and Day, A. L. - *Hot Springs of the Yellowstone National Park.* Carnegie Inst. Wash. Publ. 466, 1935.

15. - Banwell, G. I. - *Physical Investigations. Geothermal Steam for Power in New Zealand.* New Zealand Department of Scientific and Industrial Research, Bull. 177, 1955.

16. - Barth, T. - *Volcanic Geology, Hot Springs and Geysers of Iceland.* Carnegie Inst. Wash. Publ. 587, 1950.

17. - Beck, A. C., Robertson - *Geology and Geophysics. Geothermal Steam for Power in New Zealand.* New Zealand Department of Scientific and Industrial Research. Bull. 117, 1955.

18. - Bemmelen, R. W. van - *The Geology of Indonesia.* Vol. 1A. Government Printing Office, The Hague, 1949.

19. - Kimura, K., Yokojama, Y. and Ikeda, N. - *Geochemical studies on the minor constituents in mineral springs of Japan.* Union géodésique et géophysique internationale, Association Internationale d'Hydrologie Scient., Assemblée Générale de Rome, 1954, tome II.

20. - Penta, F. - *Ricerche e studi sui fenomeni esalativo-idrotermali ed il problema delle «forze endogene».* Annali di Geofisica, vol. 8, No 3, 1954.

21. - Voshioka, Toshio - *The Trend of Investigation on Electric Power Generation by Subterranean Steam in Japan.* Fünfte Weltkraftkonferenz, Wien, 1956, Paper 22 k/e.

22. - White, D. F., Sandberg, C. H. and Brannock, W. W. - *Geochemical, geophysical approaches to the problem of the utilization of hot spring water and heat. Symposium on naturally occuring thermal waters and steam and their utilization.* Proc. of the Seventh Pacific Congress of the Pacific Science Association, vol. II, Geology, Wellington, 1953.

23. - Wilson, S. H. - *Chemical Investigations. Geothermal Steam for Power in New Zealand.* New Zealand Department of Scientific and Industrial Research, Bull. 117, 1955.

Academy of sciences of the USSR
THE NATIONAL COMMITTEE FOR GEODESY
AND GEOPHYSICS
Section of volcanology

E. K. USTIEV

Aniusky volcano and localization problems of Quaternary volcanism in North-Eastern Asia

(With 1 plate)

Introduction

Geological researches of the last few decades with increasing clarity demonstrate the great importance of young tectonic movements for a correct appreciation of specific features on the Face of the Earth. Recently formulated by V. A. Obruchev (8) basic principles of a new branch of sciences — « neotectonics » — are a step forward in the understanding of laws governing the structural development of both recent and (remembering the principle of actualism) ancient continents.

Differential movements of big blocks of the earth's crust determine both the size and shape of continental masses, as well as the relief of their surface. They take place along large tectonic fractures existing in the crust for lengthy periods. Their nature and origin have been carefully analysed by A. V. Peive (9). The fruitfulness of his idea of « deep fractures » is obvious. Without this conception structural features of many areas would remain incomprehensibile for us.

Late volcanism, developing in connection with postgeosynclinal tectonic movements, also is an important element in the structural evolution of consolidated folded systems. Volcanic belts and lengthily existing deep fractures controlling them always indicate important structural trends. At the same time, they often form boundaries of large structurally individualized regions, and, in such a way delineate the main plan of geotectonic provinces. On the scale of Earth this is illustrated by the tremendous « Circle of Fire » of the Pacific ocean, in smaller scales — by a whole series of well known examples (rift volcanism of Africa, volcanicity in the Mediterranean, Iceland etc.).

A study of volcanic belts, which in a succession replaced each other on the surface of the continents, helps to reconstruct the tectonic history of the Earth. Naturally, the younger the volcanic belts, the more authentic is a similar reconstruction.

With extreme distinctness the importance of volcanic belts as boundaries between structurally different territories, is displayed in North-Eastern Asia.

As has been shown by me before (12), there is full evidence of a close connection between volcanicity and structural development here, beginning with the Upper Jurassic period. Cenozoic and especially Quaternary volcanism, inheriting certain old tectonic trends, develops also in new structural belts, associated with the latest tectonic rebuilding of the continent.

The impulse for the development of the latest ideas was given by the beautiful manifestations of Late-Quaternary volcanism on a « white spot » in the South-Aniusky range discovered from an aeroplane in 1952 and investigated by me in 1953 (Prikolymskoe Zapoliarie). This discovery induced geologists to study the problems of young volcanism in North-Eastern Asia and helped in a better understanding of the latest stages in tectonic history and magmatism.

At the same time young volcanism of the South-Aniusky mountain range is of interest by itself both because of its scale and by a unique, in this part of Asia, combination of fissure eruptions with central eruptions.

Late - Quaternary volcanism of the Monni valley

To the South-East from the lower reaches of one of the largest rivers in North-Eastern Asia — Kolyma — stretches out a vast and poorly studied mountainous region. It distinctly falls into two parallel mountain chains separated by the right tributary of Kolyma - Maly Aniuy. Extreme spurs of North-Aniusky range are truncated by the coastline of the Eastern Siberian sea. The South-Aniusky range is limited by a vast region of minor mountains on the left bank of the river Bolshoi Aniuy.

The mountain ranges, folded structures, of which they consist, and the main rivers which cut them, trend from North-West to the South-East. In the same direction are oriented the main tectonic elements, which determined the structural development of this region within a number of geological periods.

Young volcanic manifestations which have been studied in 1953 are concentrated in the valley of the river Monni, in the central part of the South-Aniusky range. Monni valley, practically throughout its entire length is parallel to the watershed line of the range and, at the same time, coincides with the axis of a big anticline in Permo-Triassic slates and sandstones.

Volcanism of Monni valley is connected with a relatively recent renewal and a further development of a number of large tectonic fractures, partly parallel to the axis of the valley (and of the anticline), partly lying at more or less steep angles to it. Some fractures were accompanied by displacements. Longitudinal disruptions are the largest; they, apparently, were developing before the others.

According to the evolution of the fissure network, there are two, also consecutively developed, types of volcanic activity in the region of Monni valley. The earlier is represented by eruptions of a linear type, while the latter — by eruptions of a central type.

Fissure eruptions of Monni valley

The first stage of volcanicity in Monny valley was characterized by big effusions of basaltoid lavas, associated with a number of lateral ruptures along the bottom of the valley.

Relatively liquid lavas pouring out quietly filled the entire bottom of the valley at a distance over 50 km and from 2 to 4 km wide. A powerful lava flow pushed the river Monni out of its bed, blocked all its tributaries and caused the formation of numerous dammed up lakes at its mouths. That is why the present drainage system of Monni valley is of an original, sort of « broken up », character; waters of the tributaries, filtering in, are accumulated into one bed only at the end of the lava stream, while all along its length the valley is devoid of a visible river.

The lava stream of this stage is about 30 m thick as an average and occupies an area about 100 sq. km; an approximate volume of the lava can be estimated at 3 km^3.

Very important is the asymmetrical shape of the lava flow, depending on an uneven distribution of the lava thickness in respect to the right (Northern) and left (Southern) slopes of the valley. The greatest thickness of the flow (up to 50 m and more) is observed at the right slope of the valley, where lavas rise for dozens of meters up the slope and by hundreds of meters penetrate into the right tributaries. On the other hand, towards the left slope of the valley, the thickness of the flow rapidly decreases (in places to zero) and there is no place where lavas would penetrate beyond the mouths of the left tributaries of the river Monni and do not rise along the gently sloping left side of the valley. As a result, the surface of the flow as a whole has a slant from the North to the South, or from the right slope of the Monni valley to the left.

Such an asymmetry could have arisen only as a result of a lava movement mainly across the valley. The mechanism of such an asymmetry can be satisfactorily explained by the fact that tectonic fractures passing along the floor of Monni valley and nearer to its right flank served as lava effluent channels. In this case the hydrostatic pressure of the lavas should have caused a swelling of the lava flow near the right slope, close of the channelway and its gradual diminution in the direction towards the further — left — slope of the valley.

This explanation is confirmed by the virtually exclusively longitudinal orientation, in respect to the axis of the valley, of swells caused by warping as a result of pressure exerted by flowing lava on the already consolidated surface of the flow. As should be expected, such swells are especially developed along the left flank of the valley towards which the main mass of the lava was rushing freely. Here double, triple and sometimes even quadruple rows of warping swells can be observed, stretching with small intervals for dozens of kilometers. The height of the swells comes to 10-15 m with a transverse section of 40-50 m. A longitudinal gaping crack caused by the subsidence of the arc passes along the axis of each swell.

Along the right bank of the valley slope, where flowing lavas soon after emerging to the surface struck an obstacle, warping swells usually had no time to form. Instead structureless piling up of lava blocks rising up the slope can be observed.

A specific feature in the morphology of a fissure stream are lava swells over linear foci of eruption similar to warping swells.

Feeders of fissure eruptions, as is known, can be observed very rarely; they are usually hidden by outpoured lava. In Monni valley, however, one can see several elongated lava ridges which, according to many signs, can be regarded as eruption centres. The largest ridge stretches for 6 km along the valley axis, approximately in the middle part of the lava flow. Several shorter eruptive centres are found near its right slope. The total extension of the discovered linear foci comes to only 15-17 km, while the length of the flow exceeds 50 km.

Each of the lava ridges — eruption centres — produces small flows overlying earlier effusions. The direction of their flow is distinctly marked by bands and arcs of ropy lavas. One of the eruption centres at the right slope of the valley is accompanied by a big flow about 0.5 km long and at least 20 m thick.

The composition of the ridges — centres of eruption — is determined as very vesicular trachybasalts of a brown and red colour. Real scoria lavas are also encountered. Such rocks are absolutely absent in the warping swells, for which, just as for the entire stream, black and much less vesicular lavas are characteristic.

The preserved linear centres of eruption are, apparently, the latest manifestations of fissure volcanism in Monni valley. The earlier channels, which produced the main bulk of lavas, are, of course, unapproachable for observation.

A very peculiar feature of the lava stream are lava lakes. These are several rounded depressions up to 15-20 m deep, located in the middle part of the stream. They differ from late sags, caused by the contraction and consolidation of the alluvial substratum, by a peculiar structure of their bottoms and ring lava crests surrounding them. Instead of block lavas of sags one finds here badly and disorderly warped undulating lavas on the surface of which there are patches of just as disorderly twisted ropy lavas. The entire picture reminds a pot with violently boiling thick tar. Bands of ropy lavas are descending from the ring crests both inside the hollows and along the external flanks of the crests.

A characteristic feature of the hollows are vertical tubular voids up to 10 mm diameter in great quantities penetrating the lavas at the bottom. These « tubular » lavas are quite like those first described by DuToit (5) in the Dragon mountains. They, undoubtedly, appeared as a result of powerful gas jets, which made their way through the melt before its congelation.

The absence of any signs of outflow of lava flows from these hollows proves that they have not been real centres of eruption. At the same time the morphology of the hollows and texture features of their lavas permit to regard them as peculiar lava lakes, arisen here for a short period at the moment of eruption.

The appearance of lava lakes can be associated with a strong phreatic explosion, caused by an especially intense generation of vapours under the incandescent lavas of the flow. As source of masses of water vapours could have been big lenses of ice in river alluvium covered by the lavas. Ring crests around the lakes are a natural consequence of such an explosion and their structure indicates that the explosions took place up to the final congelation of the flow. Abundant water vapours, penetrating through the melt, decreased its viscosity and caused a violent « boiling », distinct signs of which are reflected in the present relief of the lake bottoms.

Thus, the severe climate characterizing the entire North-Eastern Asia beginning with the Postglacial period (10) and the resulting « eternal freezing » of the substratum, definitely influenced the morphology of the lava flow and some special features in the process of lava congelation.

A transverse section of the fissure flow, which can be observed in some deep crevasses, proves that it was not formed by one eruption. In the part of the section which can be observed, two consecutive flows of the same structure can be seen (glassy crust, vesicular basalts, dense basalts, vesicular basalts). Thus, considering small lava trains at the preserved linear centres on the surface of the stream, the minimum number of eruptive phases should be three.

The period of fissure eruptions is indirectly determined by a number of circumstances. The recent alluvial deposits of Monni trough valley overlain by the lavas, a complete absence of any signs of adjustment in the drainage system to the new relief created by the eruptions, a complete absence of erosion effects in lavas on the surface of the flow and an absolute preservation of volcanic hearths (both central and fissures) — all this indicates a very recent, in any way postglacial, period when the eruptions took place.

Isolated larches which appeared in some places in the depressions of the lava stream at its borders, permit to calculate the upper limit of the age of the eruptions, which is 250-500 years. According to local legends of the inhabitants (lamuts), somewhere in the upper reaches of Bolshoi Aniuy there are places forbidden for hunting in which smoke and flames are bursting out of the ground. It is possible that this legend brought to our times the memory of volcanic eruptions in the Monni valley.

Central eruptions of Monni valley

A complete closure of tectonic rents on the floor of Monni valley by lavas squeezed out through them, meant the end of the first stage of eruptions. However, in as much as the energy of the volcanic hearth was by this time not yet exhausted, magmatic melts have broken out in another place.

The second stage of eruptions was connected with a breakthrough of lavas above the intersection of several rents, transversal to the anticline, in the headwater basin of the extreme left tributary of Monni. This time eruptions were mostly of an explosive type. A volcanic cone had grown over the narrow feeder called by me the Aniusk volcano. The breakthrough of magmatic melts took place within a small isometric granitoid intrusion, not far from its boundary with Permo-Triassic deposits. Several tectonic rents of a North-Western and North-Eastern direction intersecting here are perfectly clearly deciphered on aerial photographs.

The Aniusk volcano has the appearance of a regular bright-red cone sharply distinguished on the light-gray background of granitoids. The height of the cone is 90-120 m (from the Western and Eastern sides correspondingly), diameter of its base 490 m, diameter of the crater 300 m at an average depth of about 75 m. The dip of the external and internal flanks of the crater to the horizon is 45 and 30°. The bottom of the crater is an oval, slightly concave platform of 70 by 30 m, elongated North-Eastwardly along one of the largest tectonic rents over which the volcano had risen. A vent is clearly seen in the bottom of the crater, sealed by dense dark lavas.

The structure of the volcano permits to reconstruct its history. The burst of the vent and the beginning of the eruption were, undoubtedly, accompanied by the strongest explosions, which have thrown out to the surface tremendous quantities of loose volcanic products. The explosive character of this stage of eruptions determined the non-stratified structure of the lower part of the cone, consisting of semi-sintered red-black scoriae, red poorly cemented tuffs and pulverized volcanic material: lapilli, sands and cinder.

During the next stage, periods of explosions were replaced by relatively quiet outflows of lava. However, even in this stage the explosive activity prevailed, which is proven by a comparatively small volume of trachybasalts poured out.

Especially intense was the final stage of the activity of Aniusk volcano. It was completed by an outflow of a big amount of lava, which broke down the North-Western part of the crater and in a powerful stream rushed down, following the natural slant of the terrain.

A stream of trachybasalts filled the bed of the extreme left tributary of Monni, rose to its watershed with the second left tributary, flowed over it and along the bottom of these two small gorges reached the wide Monni valley. Here the lavas overlapped the flow of earlier fissure-eruptions and, filling the valley to its full width, flowed downwards for a distance of about 12 km. The end of the flow is marked by a cusp, rising above the fissure flow for 15-20 m. The length of the flow which flowed out of the vent of Aniusk volcano comes to 16 km and the total volume of lava 0.48 km^3 with an occupied area of 24 km^2 and an average thickness of 20 m.

At the beginning the flow consists mostly of splintery lavas of « aa » type, replaced later by undulating (pahoehoe) and block lavas. The most characteristic morphological feature of the flow is a predominantly transverse, in respect to the valley, orientation of lava warping swells. Here lies its sharp difference from the earlier fissure flow with its longitudinal orientation of this important structural element. This distinctly indicates a mostly longitudinal, in respect to the valley, movement of the lavas from the volcano and a transverse one — for lavas of fissure eruptions.

An important characteristic of Aniusk volcano is the abundance of gases in its magmatic melts. This special feature determined the predominantly explosive character of the eruptions and the abundance of loose material in its volcanic cone. This circumstance caused also the manifestation of a picturesque volcanic phenomenon — lava fountains.

Owing to a relatively small height of the cone, the slopes of the gorge, on the bottom of which it is situated, are rising for 300-500 m above the crater. The loose material ejected was settling down not only on the bottom of the gorge but also on its slopes. The main mass of pyroclastic material was dropping on the left flank, in other words to the West from the crater. Granitoids of this flank are covered by a layer of volcanic bombs, lapilli, and ashes several meters thick. The loose layer, in its turn, is covered by peculiar lava outbursts, reminding cakes badly flattened during their fall. These flat ejectamenta lie upon each other like tiles on a roof and rise upwards along the slope in a new layer up to 1.5 m thick to a height of 150-170 m above the vent of the volcano and 60 m above the nearest lip of the crater.

The composition of the ejectamenta, their structure, shape and deposition indicate that they appeared on the slope the nearest to the volcano as a result of the action of powerful lava fountains which, during one of the last moments of eruption, were ejecting spouts of incandescent liquid material impregnated by gases.

The clearly expressed Western direction of lava fountains and loose ejectamenta indicate a slanted position of the volcanic channel. Most probably it coincides with the main tectonic rent, over which the volcano has risen, and which distinctly dips in a South-Eastern direction at an angle about 80°.

Considering the suggested dip of the volcanic channel and the geometrical position of the upper rim of lava splashes as compared to the vent, an attempt has been undertaken to estimate some physical conditions in the action of lava fountains. Thesé computations permitted to approach approximated data on the maximum height of rise for lava spouts as 300-350 m over the vent, the original velocity of outbursts (90-100 m per sec.), pressure in the vent (120-150 atm.) and the minimum depth of the hearth at which explosions take place (400-450 m).

The last figure is especially interesting as it corresponds to a higher position of the vent of the volcano as compared to the floor of the Monni valley and, thus, indicates a uniformity in the level of lava flows which sealed the feeders at the floor of the valley and the explosion hearth of the volcano.

Petrology of Quaternary lavas in Monni valley

All lavas of both fissure and central eruptions belong to basaltoids. Owing to a high alkali content they could be called tephrite basalts, with which they are identical in their chemism. However, the absence in their petrographical composition of feldspathoids makes one sooner to refer them to the trachybasalt group.

By many peculiarities of their chemism all lavas of Monni valley distinctly join the Quaternary effusives of the « Eastasiatic » province, established by Koto, Tomita and A. N. Zavaritzky (6). As it is known, rocks of this specific alkaline formation are characteristic for young volcanism of Manchuria, North-Eastern China, Mongolia and the Far-Eastern Maritime Province. The establishment of effusives of this formation in the North of Asia greatly expands its geographical borders compared to previously known limits.

In spite of an extreme similarity in the petrography and chemism of Monni valley lavas, their detailed study permitted to establish some very interesting differences between them.

Lavas of fissure eruptions fully belong to basaltic trachybasalts. Early flows of Aniusk volcano consist of andesite-basaltic trachybasalts, later-again of basaltic trachybasalts and with an ever increasing basicity. Thus, there is a clear differentiation in the composition of melts, which displayed itself especially clearly in the interval between the end of fissure eruptions and the beginning of central eruptions.

Parellel with the change in chemical composition, there was also in lavas a change in the mineral composition. Especially interesting is the change in the composition of pyroxenes — from augite with 46 % of calcic metasilicate at the early stages, up to pigeonite-augite with 32 % of calcium component at the late stages of evolution. For this stage the following decay of pyroxene is characteristic with a segregation in pigeonite augite of thin lamellae of clinoenstatite and granules of magnetite.

Localization problems of Quaternary volcanism in North-Eastern Asia

Lateral rents, with which trachybasalt eruptions of Monni valley are connected, are subjected to a general structural plan of development of the Aniusk upland. Approximately lateral is here the direction of folding, of the main orographic elements, of the largest river valleys and tectonic rents. Of substantial importance in the formation of structural features of North-Eastern Prikolymie were also rents transversal to this main trend. With these are genetically associated chainlets of some granitoid Mesozoic intrusions, boundary lines of separate lifted or downcast blocks, and, finally, transverse valleys of a number of rivers.

An obvious case of a combination of sublateral and submeridional rents of the latest origin is Monni valley, in which the former served as channels for fissure eruptions and the latter were associated with the appearance of a volcano. Of a more ancient origin is a similar rhomboidal pattern of rents in the upper reaches of the river Pogynden (North-Aniusky range), to which a big block of Archean rocks is attached, uplifted and squeezed among Mesozoic geosyncline deposits.

The nearly lateral general trend of folded and disjunctive structures in the region of Aniusky ranges is sufficiently clearly coordinated with the Northern boundary of one of the most important geotectonic elements in North-Eastern

Asia — the Omolonsk Pre-Cambrian block. However, it is hardly possible that the directing influence of the rigid Omolonsk block could be the only reason for the orientation of many structural elements of the entire North-Eastern Prikolymie up to the coast of the Eastern Siberian sea and further on up to Vrangel island. Another reason which could influence their direction could be the « Giperboreisk shield » of N. S. Shatsky (13), whose idea supported by a number of Soviet geologists has found now corroboration in a number of data obtained by magnetometric surveys. These surveys have proven the existence of a tremendous area of a quiet magnetic field, extending beyond the continental slope from Novosibirsk islands up to Barrow cape on Alaska. The Southern boundary of this platform has also a direction approaching a lateral one and, in such a way, together with the Northern boundary of the Omolonsk block, can influence the structural development of the Aniusk upland. This upland is a young horst-like uplift of a block structure, limited from the West and East by Quaternary subsidences of the Kolymo-Indigirsk lowland and the Chaunsk gulf, from the North by a similar young subsidence of the Eastern Siberian sea (11), and from the South by a system of blocks of the Pre-Cambrian Omolonsk block. Epigenetic valleys entrenched for more than 100 m, denote large young uplifts in the basins of both Aniu rivers (2).

Consequently the circumstances which predetermined the outburst of Late-Quaternary volcanicity in Monni valley are connected with the lengthy structural development of arctic Prikolymie, which completed in Postglacial time by largest differential dislocations of block masses, a renewal of tectonic rents and outflows of an alkaline basaltic magma.

Authentically established manifestations of Quaternary volcanicity are known in the North-East of the USSR except Monni valley also in the basin of the river Indigirka, where on one of its tributaries — the river Moma — three small volcanic hearths have been discovered but not yet studied, which broke through a Quaternary terrace (3). With the same zone of big tectonic rents can be connected a volcano which operated in the second half of the 18th century, not yet discovered by geologists, in the vicinity of the former town Zashiversk (on the banks of Indigirka) and described in 1824 by F. P. Vrangel's companion F. F. Matiushkin (4). On the extension of this zone to the South, in the basin of the river Kolyma, manifestations of apparently Quaternary basaltoids have been discovered but not yet studied in the basin of the river Pravaia Yasachnaia.

A blanket of Quaternary basaltoid lavas is overlapping glacial deposits in the Northern part of Taigonos peninsula. Volcanic ash associated with the not yet established source of eruption, form minor blankets under the vegetative cover in the Magadan region. Supposedly Quaternary lavas have been described in the basin of Malyi Aniuy and, finally, of Quaternary age is considered to be a big, apparently crateral, funnel of Elgytkhyn lake on the Anadyr volcanic upland.

All these manifestations of Quaternary volcanicity are territorially associated with the boundaries of certain important tectonic regions of North-Eastern Asia.

In particular, volcanic manifestations in the district of Magadan, Taigonos peninsula and Anadyr volcanic plateau are attached to rents within the Okhotsk tectomagmatic belt, between the Mesozoic (Yana-Kolyma-Chukotka) and Cenozoic (Okhotsk-Nippon) geosyncline regions.

Tectonic rents are extending here mainly parallel to the boundary between two geosynclines of different age, but are partly dipping towards it at more or less steep angles. Young volcanic manifestations of the Aniusk ranges are situated just on the extension of the rent zones, diverging to the West and North-West from the Okhotsk belt. Thus, they display a double structural dependence: the rents controlling them could be regarded as boundaries of the Omolonsk Pre-Cambrian block, as well as a structural element associated with the tectonic development of the Okhotsk belt.

Quaternary volcanic structures in the basins of Indigirka and Yasachnaia are connected with the belt of deep rents at the Western boundary of one of the main geotectonic elements in North-Eastern Asia — the Kolyma middle mass. A similar tectonic position characterizes young lavas of Taigonos, found at the Southern boundary of the Omolonsk rigid block, which can be regarded as the Southern protrusion of the middle mass.

Correspondingly the volcanism of Taigonos, just as volcanism of the Aniusk upland, can be associated with rents, arising at the boundaries of the ancient block and at the same time conjugated with the rents within the limits of the mobile Okhotsk belt.

Structural conditions on the background of which the discovered manifestations of Quaternary volcanicity were developing in the North-East of Asia, have one common feature: in all cases these manifestations are caused by latest movements in lengthily existing mobile zones. Of major importance here were movements on the periphery of the Kolyma middle mass (as part of which could be considered the ancient Omolonsk block) and on the boundary of two geosynclines of different ages.

It should be said that this zone of rents at the boundary of the Kolyma middle mass and the Okhotsk zone, connecting the Yana-Kolyma-Chukotka and Okhotsk-Nippon geosynclines, were places of the greatest magmatic activity during the entire Mesozoic and Cenozoic. In particular, with the structures limiting the middle mass are associated 30-40 % of all magmatic rocks developed on the territory of the Mesozoic geosyncline. Within the Okhotsk belt are concentrated 65.2 % of the entire area of magmatic rocks in the North-East of USSR. In such a way, Quaternary volcanism serves here only as the last echo of a previously much more intense magmatism.

Geological researches of recent years indicate a big scale of tectonic movements which embraced North-Eastern Asia during the Quaternary period and which were, undoubtedly, associated with volcanic manifestations under discussion.

We have already mentioned young horst-like uplifts within the Aniusk ranges, associated with similar young subsidences on the territory of the Chaunsk gulf and the Kolyma-Indigirka lowland. In a big plan block uplifts in continental North-Eastern Asia, large in their scale, are conjugated with similarly large subsidences of a block character both inside the continent and especially on its margins.

Submarine valleys of a number of big rivers observed at the bottom of Okhotsk (7), Eastern-Siberian and Chukotsk seas (11), just as characteristic frazil ice deposits (1), indicate their Postglacial origin. A region of vast Postglacial subsidences is also the Northern part of Bering sea together with Bering straits (1, 11).

Zones of active tectonic rents on the boundaries of especially big dislocated masses, were naturally presenting most favorable conditions for the development of Late-Quaternary volcanic phenomena.

BIBLIOGRAPHY

1. - Bezrucov, P. L. and Udintzev G. V. - *New data on the geological features of Far Eastern seas.* Reports USSR Acad. of Sci., V. XCI, 2, 1933. (In Russian).
2. - Vacar, V. A. - *Geological structure of the North Eastern Pricolymie.* Trans. Arctic Inst., V. 90, 1937. (In Russian).
3. - Vasjkovsky, A. P. - *Quaternary volcano « Balagan-Tass » of the Upper Moma.* Trans. Laborat. of Volcanol. and Kamchatka Volcanol. Station, V. 6, 1949. (In Russian).
4. - Vrangel, Ph. P. - *Voyage along the Northern coasts of Siberia and in the Arctic ocean carried out in 1820, 1821, 1822, 1823 and 1824.* Glavsevmorputj, 1948. (In Russian).
5. - Du Toit, A. L. - *Pipe amigdaloids.* Geol. Mag. 4, 1907.
6. - Zavaritzky, A. N. - *On the volcanoes in the vicinity of Mergen and their lavas.* Coll. art. dedicated to the 50th anniversary of Acad. V. A. Obruchev, V. 2, 1939. (In Russian).
7. - Lindberg, G. Ch. - *Geomorphological features of Eastern Asiatic outlying seas floor and distribution of the Eastern fish.* Bull. Geograph. Soc. of Russia 3, 1946. (In Russian).
8. - Obruchev, V. A. - *Principal features of cinetics and plastics of Neotectonics.* Bull. USSR Acad. of Sci., Geol. ser. 5, 1948. (In Russian).
9. - Peive, A. V. - *General characterictic, classification and arrangement of the deep fractures.* Bull. USSR Acad. of Sci., Geol. ser. 1, 1956. (In Russian).

10. - Saks, V. N. - *Quaternary period in the Soviet Arctic.* Trans. Arctic Inst. 201, 1948. (In Russian).

11. - Saks, V. N. - *Conditions of the floor sediments formation in Arctic seas.* Trans. Inst. for the Geol. of Arctic 35, 1952. (In Russian).

12. - Ustiev, E. K. - *The Mesozoic and Cenozoic magmatism in North-Eastern USSR.* Materials on the geology of the North-East of USSR 4, 1949. (In Russian).

13. - Shatzky, N. S. - *On the Arctic tectonics.* Proceed. First geol. Conference of the Chief Northern Sea-Route Administration 1, 1935. (In Russian).

SKETCH MAP SHOWING DISTRIBUTION OF QUATERNARY VOLCANIC MANIFESTATIONS ON THE TERRITORY OF NORTH-EAST ASIA (Kamchatka excluded)

Ia - Kolyma middle mass (Northern boundary shown by dots).

Iб - Omolonsk block. Iв - Taigonos block. Iг - Okhotsk block.

Iд - North-Chukotka block. Ie - South-Chukotka block. Lines with hatchures show regions with a stable tendency to uplifts during Quaternary period.

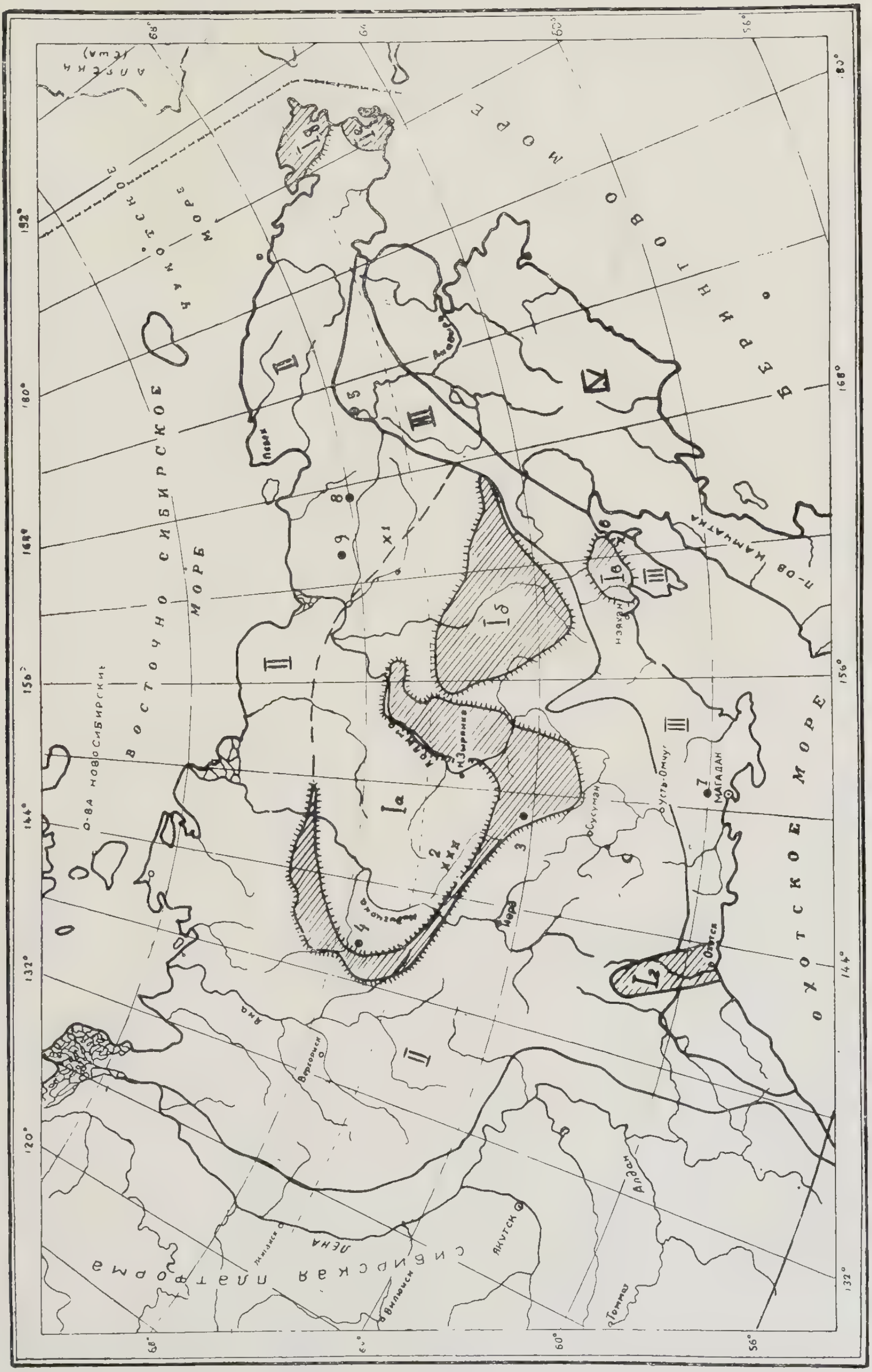
II. - Paleozoic-Mesozoic geosyncline region.

III. - Border region between two geosynclines of different periods (Okhotsk tectomagmatic zone).

IV. - Mesozoic-Cenozoic geosyncline region.

1. Aniusk Late-Quaternary volcano.
2. Group of Moma Late-Quaternary volcanic cones.
3. Suggested Quaternary lavas on Pravaia Yasachnaia river.
4. Suggested Zashiversky volcano.
5. Explosion funnel of Elgytkhyn lake.
6. Interglacial basalts of Taigonos peninsula.
7. Quaternary ashes from the vicinity of Magadan.
8. Suggested Quaternary lavas of Maly Aniuy (Upper reaches).
9. Suggested Quaternary lavas of Maly Aniuy (midstream).

. K. USTIEV — *Aniusky volcano and localization problems of Quaternary volcanism in North-Eastern Asia.*



Academy of sciences of the USSR
THE NATIONAL COMMITTEE FOR GEODESY
AND GEOPHYSICS
Section of volcanology

G. D. AFANASSIEV

Development of magmatism in the Caucasus in the light of absolute age determinations

1. History of the development of magmatism in the Caucasus and the activity of its separate stages

According to geological conclusions published in other papers, the following granitoid complexes of different ages can be segregated within the North-Caucasus folded region.

a) Caledonian intrusions of plagiogranites and plagioalaskites. The intrusions are accompanied by pegmatites and aplites, as well as by phenomena of sodium metasomatism in deep conditions.

The age of these intrusions and their derivates, according to estimates, ranges between 290 and 350 million years. The division of Caledonian magmatism into smaller stages is possible after its more detailed study with the application of other methods. Magmatic rocks of the Caledonian cycle (Urushtensky complex), together with enclosing crystalline schists, served as a substratum for all the following intrusions of younger intrusive cycles.

b) Hercynian granitoid intrusions of Upper Paleozoic of an age from 240 to 180 million years. They are displayed in different structural zones of Northern Caucasus as intrusions of a granitic magma — gray binary granites, alaskite granites of the Main ridge and the so-called red granites or Northern granites.

Derivates of this magmatic complex have also formed minor intrusions of an unequiponderant composition, which originated in hypabyssal facies conditions of Mt. Yatyrgvart etc. Hercynian magmatism is also represented by stocks and dikes of acid, essentially potassium granite-porphyries (Hudes, Indysh). Finally, during this period masses of a batholith-like character are being formed, which make up the main bulk of the so-called ancient microcline granites of the Main ridge.

The evolution of the last granitoids is of a complicated nature. A big role has been played here by processes of metasomatism — potassium metasomatism associated with Hercynian magmatic masses. Potassium metasomatism determined the reworking of the substratum and early granodioritic intrusions into microcline porphyraceous granites.

Intrusions of Hercynian alaskites from different places of Northern Caucasus	have an age of	190	mln. years
Intrusions of binary granites	»	200	»
Granite - porphyries of Hudes	»	190	»
Contaminated minor intrusions of Indysh	»	210-240	»
Minor intrusions of Yatyrgvart	»	170-214	»
Age of porphyroblast microcline in granitoids of the Main ridge (period of potassium metasomatism)	»	180-200	»

c) **Mesocenozoic intrusions** are represented by small intrusions of a granite magma, following the manifestations of the fundamental volcanogene formations. In section deeply opened up by erosion, they are accompanied by pegmatites.

Absolute age of these manifestations of magmatism is within the limits of	80-110 mln. years
Age of Liassic andesite outflows in Mt. Klukhori region	120 »

d) Tertiary intrusions.

Anorthoclase granites (measurements of 1957)	50-40 mln. years
Extrusions of « trachyliparites »	30-25 »

e) Quaternary effusions and extrusions, representing maybe the beginning of a new cycle, are not yet investigated as to their absolute age.

The paper gives description of the main stages in the intrusive and granitizing activity of North-Caucasus during the period from Lower Paleozoic until Upper Tertiary.

Available data on different vein rocks and effusives could be synchronized with intrusive manifestations.

Age data on magmatic complexes of Georgia, Armenia, Azerbaidzhan and North Caucasus already now permit to outline two large, essentially geosynclinal stages in the development of Big Caucasus.

The first stage of geosynclinal development (Cambrian-Silurian) of the Caucasian folded region is characterized by the development of the ophiolitic formation ending in intrusions of plagiogranites and Na granites. This stage corresponds to the development of a Caledonian geosyncline in the place of present Northern Caucasus.

During Upper Paleozoic — Carboniferous, Permian — in these structures a complicated granodiorite-granite complex of magmatic and metasomatic rocks is being formed, corresponding to the Hercynian stage. For magmatic and metasomatic formations of this stage an essentially potassium type of rocks is characteristic.

Altogether this entire completed cycle of development embraces about 170 million years (350-180 mln. years).

In Transcaucasia during the Jurassic-Lower Cretaceous periods a younger geosyncline is being formed. As result of its development a young ophiolite complex originates, also accompanied by plagiogranitic intrusions.

Beginning with Upper Cretaceous and up to Tertiary inclusive intrusions, relatively rich in potassium, are being formed and they end in the formation during the Tertiary of alkaline granitoids and essentially alkaline rocks, petrographically similar to some magmatic rocks of the Appennine peninsula.

The duration of this cycle of development is estimated to be 120 mln. years. Within the old geosynclinal area (Northern Caucasus) there are magmatic manifestations which are an echo of magmatic processes accompanying the formation of a geosyncline in Transcaucasia during Mesocenozoic times.

For the Urals L. N. **Ovchinnikov**, A. S. **Shur** and M. V. **Panova** have discovered with the aid of K-Ar method the following intrusive rocks: 1) Pre-Cambrian (Berdyaush rapakiwi) of an age about 1000 mln. years, 2) Caledonian stage (Kushva, Magnitogorsk, Caledonian and other masses) of an age of 350 mln. years, 3) Hercynian stage (Verkhne-Isetsky, Myrzinsky, Ilmenogorsky masses) of an age of 250 mln. years.

In Middle Asia researches based on K-Ar method disclosed caledonides of an age of 330-340 mln. years and Hercynian intrusions (Kuraminsky range) which have been formed during several intrusive phases during a period of 250-180 mln. years.

In the Maritime province of the Far East, using the same method, also caledonides of an age about 340 mln. years, hercynides of an age 200-180 mln. years and Cenozoic intrusions of an age of 60-70 mln. years have been determined. Above given data show that granitoid intrusions of Caledonian, Hercynian and Mesocenozoic (for the last three regions) stages took part in the building up of folded zones of the Urals, Caucasus, Middle Asia and the Maritime Province. The petrographic aspect of rock associations corresponding to stages of different ages in such remote regions is similar for complexes of the same age. The first results in the study of the absolute age of rocks in the Urals, permit to outline in its development also a stage more ancient than the one established for the Caucasus. This stage of magmatism corresponds to the age of about one billion years.

Detailed petrological and geological study of magmatic complexes of different ages will permit in future to establish general laws governing the development of magmatism in the earth's crust.

2. Main laws governing the development of magmatism in Northern Caucasus

In the history of the development of the North-Caucasus folded region the initial stage in the formation of a large geosynclinal trough in the Cambrian was accompanied by a powerful manifestation of volcanism, characteristic for the ophiolite formation (spilites, diabases, sodium keratophyres). As the first intrusions of granites are dated as being 350 mln. years old, the beginning of magmatic activity can be approximately referred to a period between 400 and 500 mln. years ago.

The development of folding processes, accompanied by deep fractures, brought about the formation of a complicated intrusive magmatic complex consisting of gabbro-amphibolites, ultrabasites, plagiogranites, spessartites and acid Na granitoids.

Magmatic members of the Urushtensk complex and enclosing rocks intruded by them served as substratum for all magmatic events of a Post-Devonian age.

After the completion of the evolution of the Cambrian-Silurian geosyncline, the geological development of the Northern Caucasus folded region acquired a qualitatively different character.

Deep fractures, connected originally with the formation of the geosyncline, were gradually undergoing an evolution and renewals, thus creating a regularly-zonal structure of the Caucasus.

Owing to movements, frequently having different signs, of individual zones in respect to each other, the development of new magmatic hearths is taking place in the deep parts of the crust. These hearths produce associations of rocks which are different from associations of the purely geosynclinal stage in the development of the folded region.

Consequently the deductions of the author in 1950 regarding two different types of rock associations are confirmed by more detailed researches.

1) Associations of basic and acid rocks, essentially sodium in composition, displayed both in the effusive and intrusive facies. In the intrusive facies this association includes ultrabasites. The origin of such an association of igneous rocks is connected with the development of geosyncline downwarps and the evolution of magmatic hearths in the deep zones of the earth's crust within its basaltic and maybe even peridotite shells.

2) Association, consisting in the intrusive facies of rocks mainly of a granodioritic and granitic composition. The more basic members — gabbro-diorites, diorites are formed as a result of local contamination processes of a granite magma by the material from assimilated rocks.

In the effusive facies this association is characterized by a considerable development of acid effusive rocks (liparites, dacites), quantitatively still surbordinate to the outflows of andesites and andesite-basalts.

The periodicity in the resumption of magmatic activity with the formation of specifically different magmatic complexes, including their metallogenic features, is an evidence of the palingenic origin of corresponding magmatic hearths at the expense of a local anatexis of the sial.

Very important for the understanding of petrogenetic and metallogenic processes is the establishment of the facies position of igneous bodies, in other words the conditions of transition of magmatic masses into rocks. With these processes are associated specific features in the interaction of magmas and the enclosing rocks, the character of the evacuation of volatile components from the magma.

The evolution of the Cenozoic and earlier cycles of magmatic formation of Northern Caucasus evidences to the existence of genetic relations between effusive and intrusive magmas of acid composition, which are derivates of a common magmatic source.

These relations should not be primitively regarded as a connection between the aboveground volcano and the « batholith ». The advance of magma to the upper horizons of the crust is, undoubtedly, a complicated process, proceeding through its penetration into various structural stages and a formation there of local magmatic hearths. Such a relation is easily established for intrusions, which in their invasion reached horizons near the surface of the earth. In the majority of cases such a relation is established by a specific composition and synchroneity of magmatic formations of different facies in differentially displaced blocks of one structural zone.

The depth of the formation of intrusions determines the possibility for the development of metasomatism processes - granitization.

In particular, sodium metasomatism in conditions of a deep formation of late granitoid intrusions (Cm-S) of the anticlinal structure of Peredovoi range led to the formation of metasomatic albite-oligoclase granite-gneisses, partly of a porphyroblastic texture. With analogous deep conditions for the formation of intrusive complexes are associated processes of microclinization of the Upper Paleozoic period of the structural zone of granitoids of the Main ridge.

One of essential questions of magmatic geology — the position of the lamprophyre vein series in the process of formation of intrusive complexes — receives a new elucidation on the basis of Caucasian material.

In the process of the evolution of magmatic complexes of an essentially geosynclinal type, including ultrabasites as an obligatory member, the vein melanocratic series (spessartites, in particular) form a separate stage in the formation of such complexes, which follows the invasion of the plagiogranitic (tonalite) magma, but comes before the invasion of acid differentiates—alaskites, pegmatites and aplites.

Essentially amphibolic vein rocks, as demonstrated by the study of Caucasian material, are much less subject to dynamometamorphic and metasomatic changes than their enclosing rocks of an essentially quartz-feldspathic composition.

Such a varying competence of rocks of different composition towards dynamometamorphic and metasomatic changes can lead in certain cases to erroneous conclusions on the succession in the formation of various vein rocks and the following metasomatic transformations, which took place in that or other mass.

In particular, the presence of « diabase » dikes frequently « obviously » cutting granites permits usually to consider granites, as a whole, as more ancient rocks. A detailed study of such rocks along the river Terek, for instance, and in other places, accompanied by determination of absolute age, permitted to come to different conclusions. Actually « diabase » dikes are vein spessartites intruded into the intrusions of plagiogranites before the intrusion of plagioalaskites and plagioaplites of Silurian (Lower Devonian ?) age and before the formation in these metamorphosed intrusions of porphyroblast microcline.

Cataclased intrusions of plagiogranites and spessartites of Darial gorge cutting them were subjected to microclinization. Dikes of spessartites « diabases » proved to be slightly affected by superimposed processes of dynamometamorphism and metasomatism. That is why, despite their older age, they look as cutting in respect to *microclinized porphyraceous* granites of Darial.

In this case real geological relations between rocks of different ages were veiled by superimposed processes of potassium metasomatism, described by me for another part of the Caucasus in 1949. Similar effects of microclinization for Finnish granites have been described by Edelman (1949) and for some African granites by Marmo (1955).

The Caucasus provides an example of how more detailed studies of folded regions with a complicated history of their structural-geological development permit to obtain new facts regarding the laws governing the development of magmatism. On the example of the Caucasus, owing to a disclosure of the caracter of differentiated movements of structural blocks it becomes possible to discover in different structures intermediate links between the intrusive and effusive magmatism. To prove the availability of common sources of effusive, extrusive and intrusive formations of a certain tectomagmatic period, it is important to establish their synchroneity.

At the present time it is possible to draw a conclusion that Cenozoic magmatism in the Caucasus is represented by both intrusive and effusive rocks.

On the basis of Caucasian material interesting results have been obtained to make more precise our ideas on the origin of granites.

Granites of the Main ridge were formed in deep conditions and, naturally, as long as they appeared on the surface on their own, this means that the effusive rocks, if they have been associated with the granites in the same structure, were by that time subjected to denudation. Geological-petrographic researches of the last few years succeed in demonstrating the age proximity of acid effusive rocks and porphyries (Upper Permian) of neighbouring structural subzones of Northern Caucasus with the intrusions of Upper P_z. The study of specific features of rock-forming minerals and relations between phenocrysts and the groundmass also permit to disclose peculiarities of rocks essential for the understanding of their genesis.

Some rocks of the Upper Cretaceous (Eocene?) intrusions consist to 60-80 volumetric % of crystals forming the granite skeleton of the rock, while the finely crystalline mass with patches of acid glass forms only the remaining 20-40 %.

A detailed study of such rocks shows that in this case the lengthy deep process of crystallization of a granite magma, owing to tectonic reasons, was interrupted and this mixture of 60-80% of a solid phase and 40-20% of melt was intruded into the mass of slaty clays, characterized by an extremely low endurance.

The study of porphyries and roots of extrusions usually demonstrates a reverse picture of a relation between phenocrysts of a deep origin and the groundmass of the rock crystallized after its intrusion into a higher structural horizon.

The presence of such peculiar rocks, illustrating a change in the crystallization conditions of the magma with the formation of acid volcanic glass from the remaining liquor, confirms the existence of a granite magma as a silicate melt, as well as the presence in nature of a conjugation of intrusions, extrusions and effusions of the same age — magmatic formations, connected by a common source.

At the same time data obtained on metasomatic transformations of rocks under conditions of a deep formation of intrusions with sufficient convincingness confirm out former conclusions regarding the presence of granitization processes in deep facies conditions determined by a granite magma.

3. On some results and prospects in the use of K-Ar method for the determination of the absolute age of rocks

At the present time there is a rather firmly established opinion in literature that perthitic KNa feldspar is less suitable for age determination than micas.

E. K. Gerling carried out researches for the determination of the significance played by the energy of activation, associated with the emission of argon from muscovite and biotite. The values obtained were correspondingly 92000 and 60000 small calories per gram-atom of argon. These values are comparable in size with the bond energy of the most stable chemical compounds. That is why micas, according to E. K. Gerling, are the most suitable material for age determination by the argon method. For microclines the values of activation energy connected with the emission of argon were not determined by E. K. Gerling.

E. K. Gerling's researches have shown that the *main mass of radiogenic argon* in escaping from muscovite during heating in the interval between *600-800°* and from microcline in the interval between *1000-1100°*. These data do not yet provide a single valued solution regarding the suitability of that or other mineral for age determinations.

The question of noncoincidences in the figures of ages, obtained on micas and on KNa feldspars, can not be decided comparatively simply depending upon the perthitization of feldspars. If perthitic intergrowths of potassium feldspar by albite are regarded as perthites of the solid solution decay, this process takes place in a relatively small period of time after the crystallization of minerals from high-temperature melts—solutions, during their cooling. In future it is doubtful that the planes of perthitic intergrowths could provide a greater possibility for the migration of argon, than the crystallographic directions of perfect cleavage (001) and (010), intrinsic to each KNa feldspar.

Micas also possess a very perfect cleavage, which, naturally, determine a probability of the presence of the finest cleavage planes, along which the migration of argon can be hampered no more than along the planes of decay perthites development in a microcline.

The possibility to reconstruct the lattice of KNa feldspars, — a process described in literature as « regulation of the lattice », — could be of importance to facilitate the migration of radiogenic argon. However, the dependence of « triclinization » of KNa feldspar upon time, original conditions of crystallization and later, superimposed processes is not yet clear.

Geological-petrographic studies of rocks and minerals of the Caucasus, connected with the use of K-Ar method, carried out during recent years, permit to confirm that in a number of cases this material also provides considerable discrepancies between the figures of ages, determined for minerals extracted even from one hand specimen. But this question needs a more detailed investigation.

In my article of 1955 I already pointed out the difficulties in the determination of an absolute age connected with the insufficient precision of methods used for the determination of potassium (presence of rubidium, hydration and oxidation of micas when prepared for a chemical analysis, etc.), especially if it is in small quantities. For rather old rocks this can lead to considerable deviations in the figure of absolute age.

It was also shown at the same time how important it is to take into the consideration the fact that in many granitoids porphyraceous phenocrysts of KNa feldspar, being porphyroblastic (metasomatic) formations, will be of a younger age than the substratum along which they developed.

Continued researches on absolute age have shown that together with the unsynchroneity in the formation of individual minerals in the rock, there also took place a migration of argon, owing to a superimposed influence of younger magmatic masses.

Table 1 summarizes data on the determination of the age of separate minerals from one rock, as well as determination of the age of rocks in the roof changed in contact with a definite intrusion and, finally, data on the determination of the age of petrographically typical rocks occurring as pebbles in sedimentary deposits of a definite geological age. The given figures permit to draw the following conclusions:

1) In the parts of the Caucasus which became consolidated by the moment of the intrusion of the studied igneous rocks and which were not subjected later to the influence of younger magmatic masses, the figures of age for muscovite and perthitic microcline from the same pegmatite vein, proved to be identic (190 mln. years) and corresponding to geological data regarding their age.

2) Diorites of Mt. Yatyrgvarta are transgressively overlain by Triassic deposits with the formation of a basal conglomerate from the detritus of this diorite. The age of a bulk

TABLE 1.

Age of some rocks and minerals (K-Ar method) for different geological conditions

Geological position of the rock	Mineral, rock	Content of Rb	Age in mln. years
India, Nellore Pre-Cambrian platform	muscovite	traces	540
	amazonite	0.68	510
Caucasus. Darial massif Paleozoic folded zone Superimposed processes	porphyr. granite	—	125
	Bi from it	—	195
	Mi from it	—	80
	porphyr. granite	—	130
	Bi from it	—	190
	Mi from it	—	65
	Mi granite	—	80
	Plagioalaskite « cutting » porphyraceous granites	—	200
Kassarsk massif. Ditto.	Pl from gneiss	—	235
	Mi »	—	100
	Mu from pegmatite	—	120
	KNa feldspar	—	100
Fasnalsk section	Lower Paleozoic granite	—	125
	Mu from cutting pegmatite	—	250
	KNa feldspar from same pegmatite	—	170
	granite 176	—	125
	granite 178	—	125
	granite 203	—	125
	granite	—	100
	Mi from it	0.14	95
Teberda. Zone of the Main ridge (Upper Paleozoic)	Mu from pegmatite	traces	200
	Mi from it	0.16	195
Granites of the Main ridge	Mi	—	190
	Bi	—	210
Triassic basal conglomerate	Mi granite-porphyry (pebbles)	—	210
Minor intrusions of Yatyrgvart	anorthoclase granite	—	210
	Pre-Triassic diorite	—	215
Tertiary intrusion of Tyrnyauz	Bi from granite	—	54
	feldspar from granite	—	45
	Bi from microcline granite (Paleozoic) xenolith	—	112
	Granitogneiss of the roof	—	70
	Mi alaskite of the roof (Paleozoic)	—	60
« Laccolith » of Mt. Dzhutsa	« trachyliparite »	—	25
	granite xenolith	—	35

sample of diorite proved to be 220 mln. years, of the feldspar fraction from it —215 m.y., while a bulk sample of a younger rock of granite phase yielded the age of 175-180 m.y., i.e. Post-Lower Paleozoic but Pre-Triassic intrusive rocks and their feldspathic fraction obviously did not undergo any « rejuvenation ».

3) Pebbles of pegmatoid microcline granites from Triassic conglomerates petrographically identical with Upper Paleozoic vein granites of river Hatsavitaia, r. Indysh and other localities of the Caucasus, proved to have an age of 210 m.y. This means that into Triassic conglomerates got actually Pre-Triassic granites, but not « Jurassic », as it could have been obtained by the age determination of microcline which lost 20-25 % of radiogenic argon owing to perthitization.

Along with such data which, it seems, permit to treat the figures of absolute age with full confidence, no matter whether they have been obtained on micas and feldspars or a bulk rock, there is a number of determinations, repeated several times, which testify to the influence exerted by superimposed geological processes on the preservation of radiogenic argon in minerals, which rejuvenates the mineral and does not permit to have a judgement on the period of its formation.

Geological-petrographic studies have shown that the Darial, Kassarsk and Aksautsk granitoid masses are built of strongly dynamometamorphosed rocks which were formed in the following succession: plagiogranodiorites, amphibolic spessartites, plagioalaskites and plagioaplites. After a considerable interval they were subjected to a potassium metasomatism with the development of fresh brown biotite and porphyroblastic microcline.

Age determination of plagioalaskites of the Darial mass and of the porphyraceous segregation of plagioclase in gneisses of the Kassarsk rock mass yielded figures ranging about 300 m.y. (fluctuations depending on different determinations of the negligible content in them of potassium). The biotite age from granitoid rocks of the masses proved to be

190 m.y. The age of the porphyroblastic microcline from Darial mass as average from four specimens = 80 m.y.

There is no doubt that the Darial and analogous rock masses in the axial zone of the mountain range were at least twice subjected to dynamometamorphism before the superimposition of potassium metasomatism and before the injection of Mesocenozoic intrusions into this structural zone.

One can hardly think, that these processes, which took place during the subsidence of the structural zone, were not accompanied by a considerable heating of rock masses. Considering E. K. Gerling's experimental data, this could be the only explanation why plagioalaskites with an age of about 300 m.y. « are cutting » microclined plagiogranites, the biotite from which has the age of 190 m.y. and the porphyroblasts of microcline 80 m.y. It is also worth mentioning, that the undoubtedly Paleozoic granitoids from the contact halo of the Tyrnyauz Tertiary intrusion, associated with the same structural zone, yielded a similar age figure — about 70 m.y. It is also known that at a small distance from the Darial mass of old granitoids Cenozoic granitoids are coming out to the surface. All this permits to suppose, with sufficient grounds, that in conditions of dynamometamorphism and a certainly lengthy heating of certain sections of the axial zone to which younger Cenozoic intrusions are attached, mica formed after the potassium metasomatism, as a more stable mineral, kept radiogenic argon better, while microcline preserved smaller amounts of radiogenic argon, corresponding to the early Cenozoic stage of magmatic activity in this zone.

Thus the difference in ages determined with the help of the K-Ar method for individual minerals and vein rocks in one rock mass, not corresponding to seeming geological relations between them, can, probably, be best explained by two reasons: 1) difference in time of formation of separate minerals and 2) a thermal dynamometamorphic influence of later tectomagmatic cycles on already formed rocks. A number of other examples given in the table make such a conclusion sufficiently convincing.

Researches which have been carried out have demonstrated that in all cases of an obvious influence of superimposed high-temperature processes both micas and potassium feldspar loose a certain part of radiogenic argon. In case of a comparatively low-temperature influence, at which the colouring of pleochroic haloes in micas disappears, micas apparently preserve argon to a greater extent than KNa feldspars.

A virtually 100 % migration of accumulated argon happens, probably, in case of a high-temperature and lengthy heating, determined by a close position of molten magma (gneisses from the contact halo of Tyrnyauz intrusion).

The above-said evidences on one hand that the K-Ar method using as an object of investigation one mineral of some kind without a deep knowledge of the petrology of the studied object, can not be used as an ordinary method, fit for any occasion for the stratification of igneous formations of folded regions with a complicated history of magmatism development.

At the same time the application of this method to obtain a great number of figures with a parallel detailed petrological study of igneous formations, will, undoubtedly, permit to separate by age magmatic rocks with their derivates and in a number of cases to determine the succession and character of petrogenetic processes.

Any method of age determination, based on the radioactive decay of elements, actually determines the age of the studied mineral and not of the rock as a whole. We usually assume that the figure obtained determines also the age of the rock, part of which the mineral was. As demonstrated above this is not always correct. This assumption is correct in cases where the rock is a paragenesis of minerals formed through crystallization of one melt (solution), owing to its gradual cooling, provided that in the further history of its geological existence this paragenesis will not be subjected to influences leading to a distortion of relations between the mother matter and the product of decay.

Such external influences, distorting the mentioned relations in the mineral under investigation, are quite feasible during the lengthy geological time not only for K-containing minerals, but also for minerals of the uranium-thorium series.

A mighty help in the K-Ar method should be a method appliable to the same minerals and researches, so that work using both methods could proceed concurrently.

The above said does not create any serious grounds for worry about the future prospects in the development and practical use of K-Ar method in the solution of geological problems. Even now, in its actually initial stage of application, we can use it for an objective judgement in cases when geologists widely differ in their estimates of the age of magmatic rocks. For instance, though granites of the Main ridge of the Caucasus provided differing figures on micas and the feldspar, these figures for different intrusive phases were not beyond the range of 230-180 m.y., which is confirmed by geological data on the Upper-Paleozoic age of these granites. At the same time, it is known, that earlier these granites were regarded (and even now are regarded by some geologists) as Pre-Cambrian, while certain geologists insist on their age as being Tertiary.

It is possible to assume that the value of the age figure, obtained from a well averaged even bulk sample of the rock, with a sufficient precision of measuring radiogenic argon and the amount of K, will permit to get a correct orientation in the question of the rock belonging to a definite geological system, because the differences in the age of minerals and superimposed processes facilitating the migration of argon are more frequently connected with the evolution of a single intrusive complex. The duration of this evolution rarely exceeds 50-60 m.y., which generally provides sufficient ground for certain geological premises unattainable through usual geological methods.

The age distortions, connected with the superimposition of the influence of magmatic masses of new intrusive cycles, are usually reflected in specific geological-structural conditions accompanied by peculiar petrographic phenomena and this can always be discovered in the course of detailed geological and petrographic researches. In such cases the K-Ar method, without giving the real age of the rock, helps to get an idea of the processes which took place, which is also very important.

BIBLIOGRAPHY

1. - Amirchanov, H. I., Gurvitch, I. G., Sardarov, S. S. - *The mass-spectrometric rapid method for determining absolute age of geological formations in relation to* K_{40}/Ar_{40}. Izvestia USSR Acad. of Sci., Geol. ser., No 4, 1955. (In Russian).
2. - Afanassiev, G. D. - *Age problem of magmatic rocks of the Northern Caucasus.* Izvestia USSR Acad. of Sci., Geol. ser., No 4, 1955. (In Russian).
3. - Afanassiev, G. D. - *Microclinization phenomena in granodiorite intrusions of the batholith type of the Western Caucasus.* Izvestia USSR Acad. of Sci., Geol. ser. No 3, 1949. (In Russian).
4. - Afanassiev, G. D. - *Granitoids of the ancient intrusive complexes of the North-West Caucasus.* Proceed. Geol. Inst. of USSR Acad. of Sci., vol. 69, 1950. (In Russian).
5. - Afanassjev, G. D. - *Principal results of the study of magmatic geology in the folded region of North-Western Caucasus.* Izvestia USSR Acad. of Sci., Geol. ser., No 3, 1956. (In Russian).
6. - Wasserburg, G. - *Determination of age in relation to* Ar_{40}-K_{40}. « Nuclear Geology ». New York, 1955.
7. - Gerling, E. K. - *Argon method of age determination and its application for dismembering of pre-cambrian formations of the Baltic and Ukrainian shields.* Geochemistry, No 5, 1956, Moscow. (In Russian).
8. - Afanassiev, G. D. - *La signification de la granitisation comme processus conduisant à la formation des massifs granitiques.* Congrès Géol. Intern. Alger, 1952, Section XVIII, fasc. XV, Alger, 1954.
9. - Tyrrell, G. W. - *Distribution of igneous rocks in space and time.* Bull. Geol. Soc. Amer., 1955, 66, No. 4.
10. - Turner, F. J. and Verhoogen, J. - *Igneous and Metamorphic Petrology.* 1951.
11. - Edelman, N. - *Microcline Porphyroblasts with Myrmekite Rims.* Bull. de la Com. Géol. de Finl., Helsinki, 1949.

12. - Marmo, V. - *On the microcline of the granitic rocks of central Sierra Leone.* Schweiz. Miner. und Petrol. Mit., 1955, 35, Nr. 1.
13. - Kulp, J. and Poldervaart, A. - *The metamorphic history of the Spruce Plain District.* Amer. Journ. of Sci., vol. 254, 1956.
14. - Schurmann, H. M. K., Bot, A. C. W. C., Steensma, I. I. S., Suringa, R., Eberhardt, P., Geiss, I., Gunten, H. R., Hantermans, F. G., Signer, P. - *Second preliminary note on age determination of magmatic rocks by means of radioactivity.* Geol. on mijnb., 1956, 18, No. 10.

NOTICE NECROLOGIQUE

Nous avons le regret d'annoncer le décès du Révérend Père Lejay, Membre de l'Académie des Sciences, Vice-Président de l'I.C.S.U., Directeur du Bureau Gravimétrique International, survenu le 11 Octobre 1958.

Le Directeur du Bureau Central
de Volcanologie
F. Signore

SOMMAIRE

GUSTAV HANTKE - *Übersicht über die vulkanische Tätigkeit 1954-1956* (Mit 2 Abbildungen) . . . . . . *pag.* 3

HISASHI KUNO - *Origin of Cenozoic Petrographic Provinces of Japan and Surrounding Areas* (With 12 figures) . » 37

G. S. GORSHKOV - *Gigantic eruption of the Volcano Bezymianny* (With 39 plates) . . . . . . » 77

V. I. VLODAVETZ - *On the underground structure of some Volcanoes on Kamchatka* (With 1 plate) . . . » 113

S. I. NABOKO - *Volcanic exhalations and products of their reactions as exemplified by Kamchatka-Kuriles volcanoes* » 121

V. V. IVANOV - *Present-day hydrothermal activity within the Kurile-Kamchatka Island arc and its relation to volcanicity* . . . . » 137

E. K. USTIEV - *Aniusky volcano and localization problems of Quaternary volcanism in North-Eastern Asia* (With 1 plate) . . . . » 155

G. D. AFANASSIEV - *Development of magmatism in the Caucasus in the light of absolute age determinations* . » 173

Notice nécrologique . . . . » 193

Publications de l'Association de Volcanologie
de l'Union géodésique et géophysique internationale

Bulletin Volcanologique

Série I, publiée par le Secrétaire général A. MALLADRA
volumes 12, 1924-1936.

„ II, publiée par le Secrétaire général F. SIGNORE,
volumes 20, 1937-1959.

Prix de chaque volume $ 5.00.

Catalogue of the active volcanoes of the world including solfatara fields

Part I. INDONESIA. - By M. NEUMANN VAN PADANG.
Price $ 5.00.

Part II. PHILIPPINE ISLANDS AND COCHIN CHINA.
By M. NEUMANN VAN PADANG. **Price $ 3.60.**

Part III. HAWAIIAN ISLANDS. - By Dr. GORDON A.
MACDONALD. **Price $ 3.60.**

Part IV. AFRICA AND THE RED SEA. - By J. J.
RICHARD AND M. NEUMANN VAN PADANG.
Price $ 5.00.

Part V. MELANESIA. - By N. H. FISHER. **Price $ 5.00.**

Part VI. CENTRAL AMERICA. - By F. MOOSER, H.
MEYER-ABICH AND A. R. MCBIRNEY.
Price $ 5.00.

Part VII. KURILE ISLANDS. - By G. S. GORSHKOV.
Price $ 5.00.